JOURNAL of the SOCIETY of MOTION PICTURE and TELEVISION ENGINEERS

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(With October Addendum)

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Television Bibliography

Articles on television have been part of this *Journal* for a long time, the earliest dating back to 1923. Through the years that followed, the history of this "infant" industry's growth has been set down as an integral part of the development of motion pictures, being so recognized formally in 1949 when the members approved adding the words "and Television" to the Society's name.

Since that time so many requests for a list of recent references were received by Society headquarters that a television bibliography listing all *Journal* articles on the subject from January 1940 through September 1950 was prepared. Although it will not be published in the *Journal*, sufficient copies are available without charge to all members who ask for them. Address your request to Boyce Nemec, Executive Secretary, Society of Motion Picture and Television Engineers, 342 Madison Ave., New York 17.

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Color Television

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SUMMARY: The three major systems being considered by FCC are: (1) the CBS field sequential; (2) the RCA dot sequential; and (3) the CTI line sequential system. They are mutually exclusive in that different receiver circuit arrangements are required for each. Their principal characteristics will be described and related to the general problem of providing color television service to the public. The probable design factors upon which the FCC decision will be based, such as required bandwidth versus picture fidelity and resolution, and compatibility with existing black-and-white television systems will be covered in detail.

The engineering problems which must be solved in developing a system of color television are exceedingly complex, and to discuss all of them in a single paper is obviously impossible. The most fundamental problem, however, which must be faced in the development of a broadcast color television system, is the transmission of a picture of maximum possible quality in a minimum bandwidth. All systems of color television now being proposed represent various approaches to this problem, and in order to understand these systems it is necessary to have a general understanding of its nature. The first part of this paper will, therefore, be devoted to the general subject of television systems as related to bandwidth.

Bandwidth Requirements of Color Television

It is a well-known physical law that, with the type of amplitude modulation used for television broadcasting, the amount of information which can be transmitted is directly in proportion to the available bandwidth. This law constitutes a most important limitation to television performance. The amount of information transmitted in an ordinary black-and-white television signal requires a video band of approximately 4 megacycles or about 400 times as great as that required for a reasonably high fidelity audio signal. This video bandwidth is translated by the modulation process to radio-frequency bandwidth, and with single sideband amplitude modulation 6 megacycles of space in the radio-frequency spectrum is required to transmit a 4-megacycle video signal plus the accompanying audio channel on a separate transmitter.

Presented: April 24, 1950, at the SMPTE Convention in Chicago.

Because of the serious shortage of available spectrum space, the problem of utilizing it to its utmost is probably the most serious facing the television engineer. A tremendous amount of ingenious research has been devoted to this problem, some of the most important results of which will be discussed here.

In a black-and-white television picture the information to be transmitted is the variation in brightness of various portions of the picture. The number of independent brightness values per second which can be transmitted is equal to twice the highest frequency passed by the system. Each one-half cycle period of time is sometimes called a Nyquist interval. With the standard monochrome television broadcast system, the highest frequency is 4 megacycles and the Nyquist interval is one-eighth of a microsecond. This means that the maximum number of independent brightness values (which is usually expressed as the number of picture elements) will be 8,000,000 per second. This number represents the product of the number of picture elements in a single picture and the number of pictures which are transmitted each second. It is quite apparent, therefore, that the smaller the number of pictures per second, the larger will be the number of picture elements and correspondingly the greater the resolution of the picture. For this reason it is desirable to transmit as few pictures per second as possible. The limit to the minimum number of pictures which can be transmitted per second is set by the factors of flicker and the blurring of moving objects. Of these, the problem of flicker is the more important and has received the greater amount of attention.

With standard monochrome television, the problem of flicker has been reduced by using an interlaced scanning system. In this system alternate lines are scanned during a period of one-sixtieth of a second. During the next one-sixtieth of a second, the other set of alternate lines is scanned so that the complete picture is transmitted in a period of one-thirtieth of a second. Because of the method of interlaced scanning, however, it has been determined that the large-area flicker is probably no more objectionable than would be the case if the complete picture were transmitted 60 times a second, though a less visible "interline flicker" is introduced, particularly when the received picture is bright. This 2-to-1 system of interlace, therefore, doubles the number of picture elements which can be transmitted within a given bandwidth.

In a 4-megacycle bandwidth capable of transmitting 8,000,000 picture elements per second and picture repetition rate of 30 per second, the maximum theoretical number of picture elements per

picture would be 266,000. This theoretical maximum is not reached in practice, however. There is a reduction of approximately 14% due to the time consumed during the horizontal blanking interval at the end of each line, and a reduction of approximately 8% due to the vertical blanking interval at the end of each field. From these considerations alone the picture elements which theoretically can be transmitted in a black-and-white picture are approximately 79% of 266,000 or about 210,000. There is an additional reduction factor which is due to the fact that *vertical* variations in brightness cannot occur at arbitrary positions but can occur only from one line to the next. Since the position of the scanning lines may not coincide exactly with the variations in brightness of the picture, the effective vertical resolution is not equal to the number of visible scanning lines. A factor of approximately 0.7 is normally used to express the reduction in resolution from this source. When these factors are all combined, the total number of picture elements which can be practically resolved is found to be about 147,000. This figure is equal to the product of the number of lines which can be resolved in the vertical direction which is about 338 ($525 \times 0.92 \times 0.7$) and the horizontal direction which is about 437 (63.5 μsec (microseconds) $\times$ 0.86 $\times$ 8 lines/μsec). When allowance is made for the 4-to-3 aspect ratio, the number-of-lines resolution in a horizontal distance equal to the height of the picture is computed to be 328 which is almost identical with the vertical.

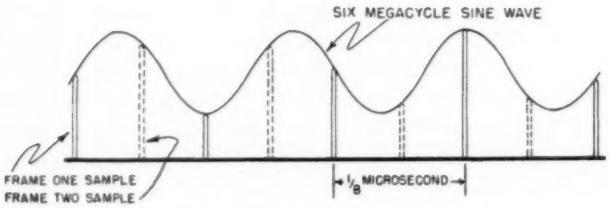
HORIZONTAL INTERLACE

Since vertical interlace can be used to double the resolution of a picture for a given bandwidth, it is suggested that the resolution might be doubled again by using horizontal interlace also. This technique has been discussed at length in recent testimony before the FCC (Federal Communications Commission) in connection with the proceedings on color television and also in the literature.*

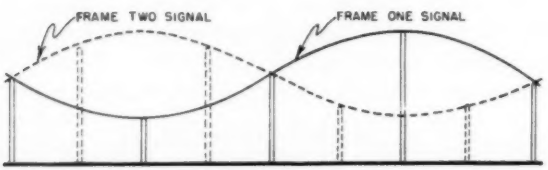
The fundamental objective to be achieved by this type of horizontal interlace is to cut the rate of picture transmission in half, thereby doubling the number of picture elements which can be transmitted in each picture. To accomplish this, the waveform to be transmitted is first sampled at approximately twice the highest frequency which can be transmitted. This is illustrated in Fig. 1 which shows a 6-megacycle sine wave sampled at the rate of 8 mega-

* Wilson Boothroyd, "Dot systems of color television," *Electronics*, Pt. I, vol. 22, no. 12, pp. 88–92, Dec. 1949; Pt. II, vol. 23, no. 1, pp. 96–99, Jan. 1950.

cycles, that is, a train of pulses having a repetition rate of 8 megacycles is amplitude modulated so that the height of each pulse is equal to the amplitude of the signal at that instant. In the television application, this sine wave would represent the output of the camera along one line of the picture. During the succeeding frame, assuming that no motion has occurred in the picture, this same sine wave will occur, and it is again sampled at the rate of 8 megacycles, but with the sampling points shifted by one-half cycle as indicated by the dotted lines. When pulses, amplitude modulated by a signal of greater frequency than 4 megacycles, are passed through amplifier



(a) ORIGINAL SIGNAL AND TRANSMITTER SAMPLES



(b) TRANSMITTED SIGNALS AND RECEIVER SAMPLES

Figure 1.

circuits having a bandwidth of only 4 megacycles, mathematical analysis shows that the only frequencies passed will be the d-c component and a component equal in frequency to the difference between the signal and the sampling frequencies. Thus in this case, the transmitted signal for both frames will consist of a d-c component plus a 2-megacycle frequency. These 2-megacycle components, however, will be 180 deg out of phase as indicated in Fig. 1(b).

At the receiver, these 2-megacycle components are again sampled in synchronism with the transmitter, thus reconstructing the transmitter samples as indicated in Fig. 1(b). At this point, a number of mechanisms could be employed to present this information on the

kinescope—perhaps the most obvious of which would be to use these narrow samples to control the magnitude of a wider pulse occupying approximately $\frac{1}{16}$ μsec in the signal applied to the kinescope. This would result in a series of dots being produced on the screen with the spaces between the dots being filled in alternate fields. In this way, it would be possible to have independent signal components occurring at the equivalent rate of 16 million per second which is equivalent to a bandwidth of 8 megacycles without horizontal interlacing. A more careful analysis indicates, however, that this process is not necessary. Instead, it is only required to pass the sample pulses through a filter, passing all frequencies up to but not including the sampling frequency. When this is done, it can be shown that two frequency components will appear in the output: first, the original signal frequency, 6 megacycles in this case; and second, the difference frequency, 2 megacycles in this case. In the succeeding frame, the difference frequency will again appear but 180 deg out of phase with respect to the first frame. If the sample output from the first frame is stored and added to the output of the second frame, the difference frequency components will cancel out, thus leaving only the signal frequency component. A cathode-ray tube with a phosphor of sufficient persistence when combined with the natural persistence of the eye provides a method for storing and adding these signals, the only limitation being that the negative values of brightness cannot be physically achieved. Consequently, if the output of the sampling circuit is applied directly to the control grid of the kinescope through a filter as described above, the signal components will be automatically produced correctly. As in the case of line interlace a new form of flicker will appear, "inter-dot" flicker, which is most visible with vertical arrays of dots, or vertical or diagonal lines, in the picture.

In the example given above, a specific frequency component of 6 megacycles was used for illustration. The following general description can be made for other frequencies. Assuming again that the transmission system will pass components from 0 to 4 megacycles and that the sampling rate is 8 megacycles, signal components from 0 to 4 megacycles will be unaffected by the sampling process and will be transmitted in the usual manner. Signal components from 4 to 8 megacycles will beat with the 8 megacycle sampling frequency and will appear in the transmitted signal as a difference frequency. These difference frequencies will likewise follow in the range from 0 to 4 megacycles. However, when resampled at the receiver, they are distinguishable from the original signal components by the fact that

on alternate frames, they will be 180 deg out of phase so that when they are sampled at the receiver the original signal frequency is restored.

When transmitting a color picture, in addition to variations in brightness, variations in color must also be transmitted. It might be thought, therefore, that the bandwidth required to transmit three primary colors would be three times as great as that required for black-and-white. Early experiments in color television followed this theory. At that time two methods were under consideration: the field-sequential system and the simultaneous system. In the simultaneous system, the three color signals were sent over separate channels so that the total bandwidth required was nearly three times that required for single black-and-white transmission. (The total was not quite three times as great, inasmuch as a reduced bandwidth was used for the blue signal; this could be done because the eye is not so sensitive to detail in blue.) In the field-sequential system, the successive fields were transmitted cyclically in the three primary colors, but when this was done it was found necessary to increase the field rate to approximately three times the black-and-white rate in order to avoid objectionable color flicker. This resulted in a nearly threefold increase in bandwidth to achieve the same picture resolution.

A closer analysis of the situation, however, indicated that this increase in bandwidth for the transmission of color is not inherently required. If a scheme could be worked out whereby a smaller number of pictures could be transmitted per second without objectionable flicker, the resolution of standard black-and-white could be maintained. Two of the three systems of color television now proposed to the FCC attempt to slow down the rate of picture transmission without a corresponding increase in flicker. These methods will be described later in connection with the individual systems proposed.

SEQUENTIAL METHODS OF COLOR TELEVISION

The simultaneous method of color television has now been abandoned for broadcast television because of its excessively large bandwidth requirements, and all three systems now proposed are sequential in nature; that is, the color information is sent in cyclical sequence and the retentivity of the human eye is employed to produce the illusion of a continuous color picture. The essential difference between the three systems lies in the color switching rate. This is illustrated in Fig. 2. On the left side of this figure is shown in schematic form the field-sequential system proposed by CBS (Columbia Broadcasting System). In this system, a complete field is

transmitted in one color. The following field is sent in the second color and the following field in the third, and so forth.

In the center of the figure is illustrated the line-sequential system proposed by CTI (Color Television, Inc.). In this system the color is changed at the end of each line so that each field contains a third of its scanning lines in each primary color.

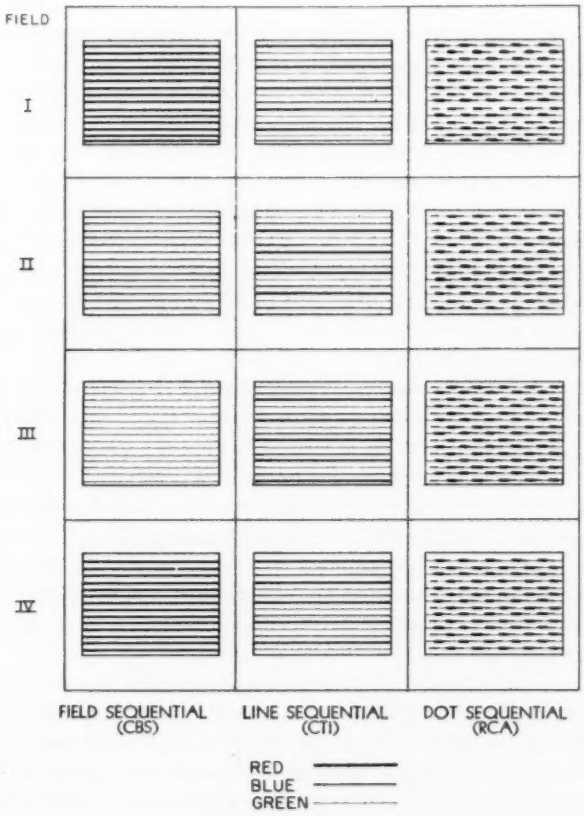


Figure 2.

On the right side of the figure is shown the dot-sequential system proposed by RCA (Radio Corporation of America). In this system, the color is switched many times during each line. The rate currently proposed by RCA is to complete the color cycle in a period corresponding to a frequency of 3.6 megacycles.

The extreme difference in the color switching rate between the RCA system on one hand and the CBS on the other is such that the terminal apparatus suitable for the three systems differs considerably. These apparatus differences have tended to obscure the more fundamental difference in the color switching rate, which is the basic distinction between the three systems.

THE FIELD-SEQUENTIAL SYSTEM (CBS)

As stated above, CBS employs the field-sequential system wherein a complete field is transmitted in one color and the color change is made during the vertical blanking period. In order to avoid flicker, it has been found necessary to increase the field rate from the standard 60/sec employed by black-and-white television to 144/sec. Two fields are required to transmit the entire picture in a single primary color and 6 fields are required to transmit a complete color picture. There are, therefore, 24 color pictures transmitted each second, corresponding nicely to the current 35-mm motion picture frame rate (although it must be admitted that such "compatibility" is of far less importance than "compatibility" with present black-and-white television, discussed below).

Because the field rate has been increased from 60 to 144/sec with no change in the interlace pattern, there is an inevitable decrease in resolution in the ratio of 60 to 144. This decrease in resolution is divided between the vertical and horizontal directions. The vertical resolution is reduced by decreasing the number of scanning lines from 525 to 405, a reduction of approximately 27%. A single line occupies 34.4 μsec as compared to 63.5 for present black-and-white. The number of Nyquist intervals in this period is, of course, reduced in the same ratio so that the horizontal resolution is reduced by approximately 46%.

In order to increase the horizontal resolution of the picture, a system of horizontal interlace somewhat similar to that described above, has been proposed by Dr. Peter Goldmark, inventor of the CBS system. This will restore the horizontal resolution to approximately the same value which exists for standard monochrome. It should be pointed out that this signal can be received without substantial degradation by a receiver not equipped with a sampling circuit. The resolution obtained in this case, of course, is not improved by the interlace process.

Since the CBS field rate is different from that employed by standard black-and-white, it is not a "compatible" system; that is, standard black-and-white receivers are unable to receive the CBS transmissions

even as black-and-white pictures without the addition of a special scanning adapter which will cause the receiver sweep circuit to operate in synchronism with the transmitter at the increased rate necessary. Messrs. Chapin and Roberts of the FCC Laboratory Division have developed an automatic adapter for the CBS system which is said to make it possible for the receiver sweep circuits to operate automatically in synchronism with the transmitter no matter which field rate is being transmitted. The installation of this device in a new receiver would, of course, increase its cost somewhat, and to adapt sets which have already been installed would cost somewhat more. This fact, plus the operational confusion which would result with dual standards, has perhaps been the source of the most severe criticism of the CBS system.

The CBS system employs the slowest color switching rate of the three and because of this it is the only system which can accomplish it by mechanical means. It has somewhat unfairly been accused of being inherently mechanical. This accusation is not fair inasmuch as any of the electronic terminal equipment, as employed by the other systems, could be used by CBS when suitably modified. Moreover, the possibility of color switching mechanically leads to certain definite advantages over all-electronic methods.

Some of the camera pickup equipment which could be used by CBS is illustrated in Fig. 3. At the top of this figure is shown the mechanical method which has been used almost exclusively by CBS in its experiments. With this device, a disc divided into segments covered with various color filters is rotated in front of the pickup tube. The shape of the filter segments and the speed of rotation of the disc is chosen in such a way that during each field a filter of given color will be in front of the pickup tube.

In the second drawing shown as Fig. 3(b), a system somewhat similar to that employed by CTI, has been adapted for use with the field-sequential system. Three lenses placed one above the other and each provided with a filter for one of the three primary colors focus three images on the light sensitive surface of the pickup tube. The horizontal sweep on the pickup tube is made to operate at its normal rate, but the vertical sweep operates at one-third the field frequency so that during one vertical period all three images are scanned. If the vertical sweep is perfectly linear and the images are properly positioned, a suitable field-sequential signal is created.

Figure 3(d) shows the camera employed by RCA. Here a single lens is used and the light emerging from the lens is made to pass through crossed dichroic mirrors. These mirrors transmit green

light directly to the center tube, one of them reflects red light to one of the tubes on the side while the other reflects blue light. Thus each of the three pickup tubes is illuminated constantly with light from one of the three primary colors. The outputs of the sweep circuits are applied to the deflection coils on the three tubes connected in parallel so that identical voltages are applied to each. Thus three signals are available constantly, one from each of the three tubes. In order to adapt this camera to the field-sequential system, it is only necessary to employ a gating circuit which will pass the output of

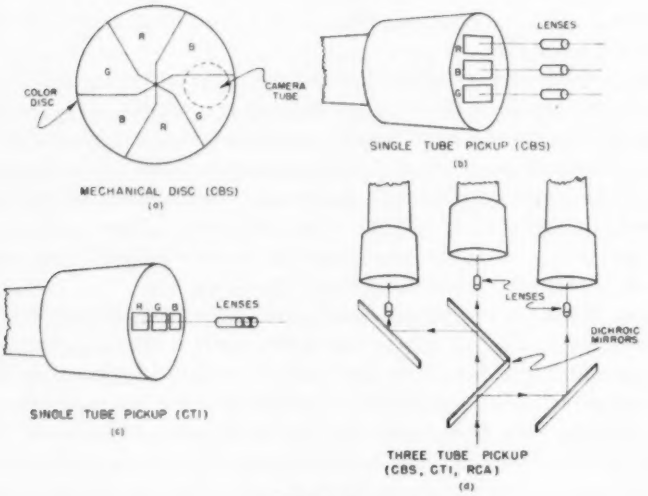


Figure 3.

each of the three camera tubes in sequence, switching at the end of each field.

In its demonstration CBS has used a mechanical system almost exclusively. This is probably due to the fact that only one tube is required and the fact that optical and electronic registration problems are avoided. The problems of registration are undoubtedly the most serious for electronic methods of color television and this is neatly solved by a mechanical disc.

The possible types of receivers which might be used with the CBS system are shown in Fig. 4. Figure 4(a) shows the mechanical method which is analogous to the system employed at the camera.

Here a disc divided into filter segments is rotated in front of the kinescope. This disc is synchronized in such a way that the red filter is in front of the picture tube when the red signal is being transmitted, the blue for the blue signal, and so forth. The eye then blends all three impressions together as a single colored picture.

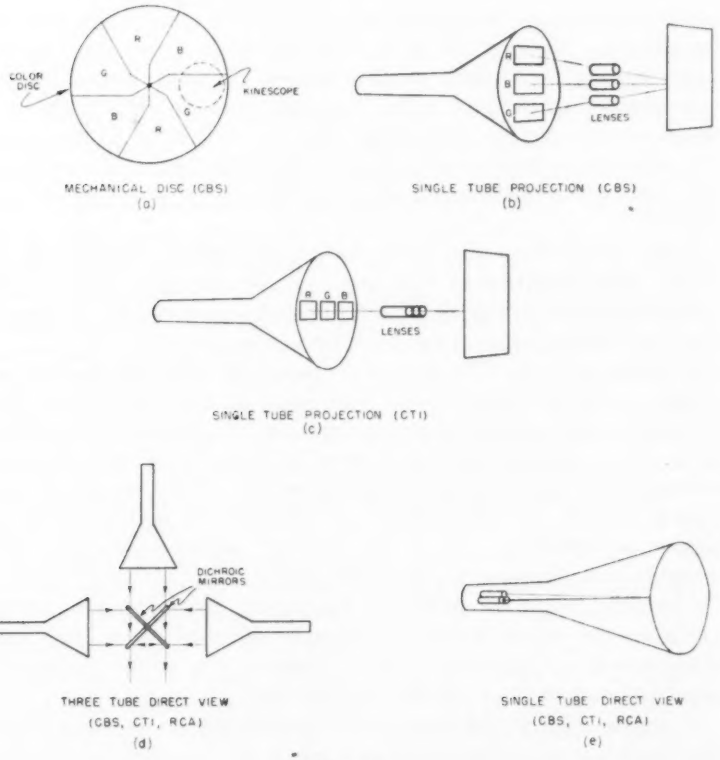


Figure 4.

Figure 4(b) shows a scheme similar to that shown on Fig. 3(b) for the camera. The phosphors on the face of the tube are deposited in three strips one above the other, each phosphor being chosen in such a way that the light emitted from it corresponds approximately to one of the primary colors. (In practice fairly good green and blue primaries can be achieved. The red primary at present contains too much yellow-green and a negative yellow-green filter is normally used.) The three images thus produced on the face of the tube are

superimposed by means of a lens system upon a projection screen, either reflecting or translucent, thus producing a color picture. Figure 4(d) shows a color receiver developed by RCA but which can also be adapted for use by CBS. Here three kinescopes are used. One of the tubes is viewed directly through a dichroic mirror while the virtual images of the other two are superimposed upon this direct image by means of the dichroic mirrors. These mirrors also provide the necessary filtering action so that one of the tubes provides an image in each of the three primary colors. The two virtual images superimposed on the face of the three tubes provide the illusion of a complete color picture. To adapt this receiver for the CBS system, it is only necessary to gate the input to the tubes so that the red tube operates with the red signal and the green with the green signal, and so forth.

Figure 4(e) shows the direct-view tube recently announced by RCA. The operation of this tube will be described later. This tube although developed by RCA for use in connection with its system could be adapted with ease to the CBS system.

Of these methods, CBS has used extensively only the mechanical system. The direct-view color tube has just been announced and has not been available for experimentation by companies other than RCA. As compared with the other two electronic methods, the mechanical system has the advantage of providing a means of producing a direct-view color picture at relatively low cost and with no registration problem. As in the case of camera equipment, the problem of registration is a very difficult one with electronic systems. On the other hand, the color disc has certain disadvantages, among which are its awkward size, and the fact that its use is limited to kinescopes of approximately 10-in. diameter due to the peripheral speed and awkward size of the whirling disc.

When the receiver and transmitter are operating on the same power line frequency, a synchronous motor can be used to operate the color disc. This will automatically stay in synchronism with the transmitter once it is set. In the case of the network programs where the problem of nonsynchronous power supply arises, it is necessary to transmit a phasing signal to keep the two in step. This signal as proposed by CBS consists of a series of impulses transmitted during the vertical blanking interval. By suitable circuitry, this impulse is made to operate the motor at the receiver in synchronism with the transmitter. The exact method to be used by CBS has not been disclosed.

THE CTI LINE-SEQUENTIAL SYSTEM

The line-sequential system proposed by CTI switches colors between (successive) lines during the horizontal blanking interval and in a given field, the lines are cyclically scanned in the three primary colors. Three possible sequences can be followed from frame to frame: a given line can always be traced in the same color, it can be traced in two of the primary colors or it can be traced in all three of the primary colors. Since 525 is (integrally) divisible by three, if a cyclic order were continuously maintained in color switching, the first situation would automatically follow; for example, the first line would always be in red, the second in green and the third in blue, and so forth. If during the vertical blanking interval, the cycle is upset so that, for example, one of the green lines is omitted, the "phase" of the color cycle will be shifted by one-third of a cycle. When this is done, a line which is scanned in red the first time can be scanned in blue the second and in green the third. This color shift is accomplished during the vertical blanking interval so that the shift in the color cycle is not noticeable. If one shift is performed every three fields, each line will eventually be scanned in two of the primary colors. This method of operation has, therefore, been termed by CTI, the "single-shift." If such a color shift is made during two out of three vertical blanking periods, each line will be scanned in all three primary colors and this method of operation has been termed by CTI as the "double-shift."

In a double-shift system, each line is scanned in all three colors and the color picture is, therefore, complete. With a single shift, one color is missing from each of the three lines. This has two effects: The vertical resolution of the picture is reduced by some amount, the exact reduction depending somewhat on the degree of saturation of the picture. If the picture consists of a single primary color, one-third of the lines will be black and the vertical resolution will be reduced by one-third. The reduction of vertical resolution for colors consisting of a mixture of primaries will be somewhat less. The second effect is the fact that the black lines will tend to show in the simple primary colors, and that the lines will be colored even when a white object appears in the picture. This is probably not a serious defect inasmuch as the eye is not sensitive to colors in such small areas as a single scanning line and the integrated effect of all the lines produces the proper color sensation at the eye, at least at a great enough viewing distance. With no shift in the color cycle, the same effects will occur except to a greater degree. The reduction in verti-

cal resolution with no color shift is so great that it has not been seriously proposed.

The choice of a proper scanning sequence is very important for the operation of the line-sequential system and a large number of combinations have been tried. Two of these are shown in Fig. 5, the first of which is a single-shift pattern in which each line is scanned in two of the primary colors while the second is a double-shift pattern in which each line is scanned in all three of the primary colors.

A third scanning sequence has recently been demonstrated by CTI which is described as the "interlaced shift." This is a double-

LINE ↓ FIELD →	I	II	III	IV	V	VI	VII
1	RED		GREEN		RED		GREEN
2		BLUE		RED		BLUE	
3	GREEN		BLUE		GREEN		BLUE
4		RED		GREEN		RED	
5	BLUE		RED		BLUE		RED
6		GREEN		BLUE		GREEN	
7	RED		GREEN		RED		GREEN
8		BLUE		RED		BLUE	

SINGLE SHIFT

LINE ↓ FIELD →	I	II	III	IV	V	VI	VII
1	RED		GREEN		BLUE		RED
2		GREEN		RED		BLUE	
3	GREEN		BLUE		RED		GREEN
4		BLUE		GREEN		RED	
5	BLUE		RED		GREEN		BLUE
6		RED		BLUE		GREEN	
7	RED		GREEN		BLUE		RED
8		GREEN		RED		BLUE	

DOUBLE SHIFT

Figure 5.

shift pattern in that each line is ultimately scanned in all three colors with six fields being required for a complete color picture. It departs from the standard interlace in that odd lines are scanned during three successive fields and the even lines on the next three. The purpose of this shift is to mitigate line crawl. This is accomplished by employing a sequence wherein continuous upward and downward motions of lines of each color occur simultaneously. While either of these motions can be seen if specifically looked for, the effects of the two cancel out as soon as the observer concentrates on the subject matter rather than the line structure. This sequence has been described by CTI as the best of all it has tried.

The line-sequential system as advocated by CTI employes the same number of fields per second, the same number of lines, and the same 2-to-1 interlace employed by standard black-and-white television. This, therefore, is a compatible system in that ordinary black-and-white receivers can receive the transmission in black-and-white without any changes or adjustments necessary.

Since the period occupied by one line is the same as for standard black-and-white transmission, the number of Nyquist intervals in one line is the same and the horizontal resolution is likewise identical. If the double-shift pattern is used, the vertical resolution is likewise identical while if the single shift is used, the vertical resolution is reduced by some factor which may be as high as one-third.

Any of the electronic cameras described in connection with the CBS system can be used with the CTI. The camera shown in Fig. 3(b) is modified by placing the three images side by side on the photosensitive surface rather than one above the other. The vertical sweep frequency is at the normal rate but the horizontal sweep is reduced to one-third of the standard value. Thus as the electron beam scans across the mosaic it strikes successively, a red, green and blue image area thus providing modulation for a red line, a green line and a blue line in order. At the end of the field any desired change in shift in the color cycle can be made so that the colors in the next field will be scanned in the desired order.

The three-tube camera can also be used (Fig. 3(d)). Here it is only necessary to switch the output of the three cameras in such a way that the red signal is transmitted for one line, the green signal for the next, the blue for the next, and so forth.

So far in its demonstrations, CTI has employed the single-tube type of pickup. This, of course, is considerably cheaper than the three-tube system employed by RCA. However, the problem of making the sweep sufficiently linear so that the three images can be maintained in proper registry has been quite bothersome, and it may be that the three-tube camera can be operated with greater ease. Also, the resolving power of existing orthicons provides a limitation to the resolution of the picture which can be obtained when three small images are placed side by side on the photosensitive surface.

Any of the electronic receivers described in connection with the CBS system can be used for the CTI line-sequential system. In the case of the single-tube projection receiver, the three colored images are placed side by side rather than one on top of the other (Fig. 4(c)). The vertical sweep operates at the normal rate while the horizontal operates at one-third of this value. With the RCA three-tube

receiver (Fig. 4(d)) it is only necessary to gate the input to the three tubes so that the red signal actuates the red tube for one line, the green for one line and the blue for another, and so forth. The RCA direct-view color tube (Fig. 4(e)) can also be used with the CTI line-sequential system. None of these tubes have been available to CTI as yet for experimentation. However, it seems apparent that the simplicity and direct-view characteristics of this will make it or some direct-view tube the ultimate answer to the receiver problem for the line-sequential system.

When the double shift is used, six fields occupying one-tenth of a second are required to trace every line in each of the primary colors. It is by thus slowing down the rate of transmitting the complete color information that CTI is able to maintain the resolution of black-and-white and transmit color in addition. With the field-sequential method, slowing down the picture repetition rate to this speed has resulted in very objectionable flicker. By switching colors at the end of each line, the flickering elements are broken up into lines rather than fields and are thus very much less noticeable to the eye. The crucial question in connection with the line-sequential system is whether this rate of color switching is sufficiently rapid or involves a small enough area to reduce flicker to an unobjectionable value. With certain scanning sequences and with certain types of subject material an objectionable line crawl or interline flicker seems to occur. Critics of this system contend that this is an inherent flaw in the system which cannot be solved by any apparatus refinement. Whether or not this is true has not been definitely established and, as indicated above, it is probably upon this factor that the success or failure of the line-sequential system will depend.

When the single shift is employed, a cycle is completed in four fields or one-fifteenth of a second. As might be expected, such a pattern is less susceptible to line crawl or flicker than the double shift. Again, no definitive answer has been determined with regard to the seriousness of the flicker problem with the single shift.

As compared with the RCA system, to be described later, the CTI system has the obvious advantage of much less complexity, plus the fact that it can operate in a system of reduced bandwidth such as existing coaxial cable with the natural loss in resolution but with no loss in color values. The main question with regard to this system is whether this simplicity has been achieved at too great a loss in performance. Until the question of interline crawl or flicker and its effect on picture quality has been definitely determined, it will be impossible to say whether or not this is the case.

THE RCA COLOR TELEVISION SYSTEM

The RCA color television system employs the most rapid color switching rate of the three sequential systems which have been proposed. For this reason, as might be expected, it is the most complex of the three, both with respect to the studio and receiving equipment. This system is, indeed, a marvel of ingenuity.

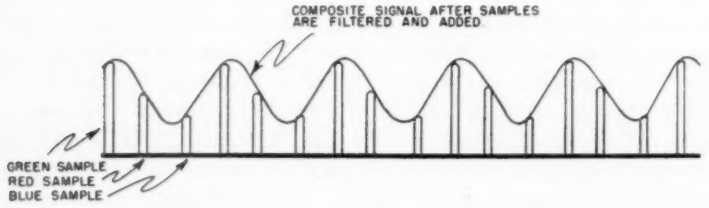
In its present form, the RCA color camera consists of three pickup tubes arranged as shown in Fig. 3(d) which provide simultaneously red, green and blue electrical signals. Each of these signals is first passed through a filter which separates the components below and above 2 megacycles. The high-frequency components from 2 to 4 megacycles are combined and are transmitted without color separation. This procedure is justified by RCA on the grounds that the eye is not sensitive to colors in the fine detail represented by the high-frequency components in the picture; consequently, it is not necessary to transmit this detail in color. This has been termed the "mixed highs" principle by RCA.

The three color signals containing frequency components up to 2 megacycles are then sampled at the rate of 3.6 megacycles, that is, during the period corresponding to one cycle of this frequency all three colors are sampled. The amplitude of each pulse sample is proportional to the corresponding magnitude of each of the primary colors in this portion of the picture. The sample pulses are then combined and passed through a filter which removes all frequency components above 4 megacycles. As a result, the 3.6 megacycle sine wave is produced as shown in Fig. 6(a). Examination of this figure indicates qualitatively that the phase of the resulting wave will be determined by the predominant color in the picture, the magnitude of the wave will depend on the difference between the highest and lowest samples, while the d-c level of the wave will depend on the average level of the three components. More precisely, it may be said that the hue of the picture is determined by the phase of the color wave, the saturation of the color is determined by the amplitude of the color wave, and the brightness of the picture is determined by the d-c content of the wave.

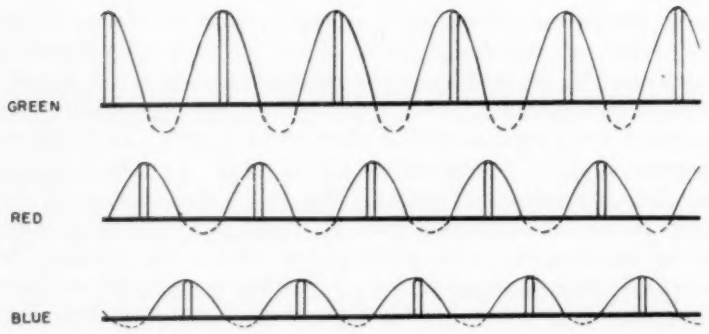
The color wave is combined with the "mixed highs" signal and both are then fed to the transmitter input and the signal is transmitted in the usual fashion.

At the receiver, the converse of this action occurs. The transmitted wave is first amplified and detected in the usual manner. The resulting video signal is then sampled in synchronism with the

transmitter and as a consequence, three sets of sampling pulses are made available—one for each color. These pulses are then passed through a low pass filter which results in a 3.6-megacycle sine wave, the amplitude of which is proportional to the amplitude of the sample pulses. This process is illustrated in Fig. 6(b). These signals are then combined with the "mixed highs" and the resulting signals are ready for application to the kinescopes or color tube.



(a) TRANSMITTER SAMPLES AND TRANSMITTED WAVE.



(b) RECEIVER SAMPLES AND KINESCOPE SIGNALS.

Figure 6.

In the case of the three-kinescope receiver illustrated in Fig. 4(d), each of these signals is applied to the corresponding kinescope grid. The sinusoidal form of this signal results in a series of dots being produced on the kinescope and when these three sets of dots are combined, the result is the dot-sequential color presentation illustrated in Fig. 2.

In the case of the direct-view color tube recently demonstrated by

RCA, the three signals are all applied to a single tube in a manner which will become apparent later when this tube is described.

In order that each portion of the screen be excited eventually with all of the three colors, it is necessary to shift the phase of the color cycle so that on succeeding frames, each portion of the screen will be excited sequentially in the three colors. If there were no overlap between the dots, it would require three frames in which to do this; however, because the width of the dots is about one and one-half times the distance between them, it is possible to cover the entire

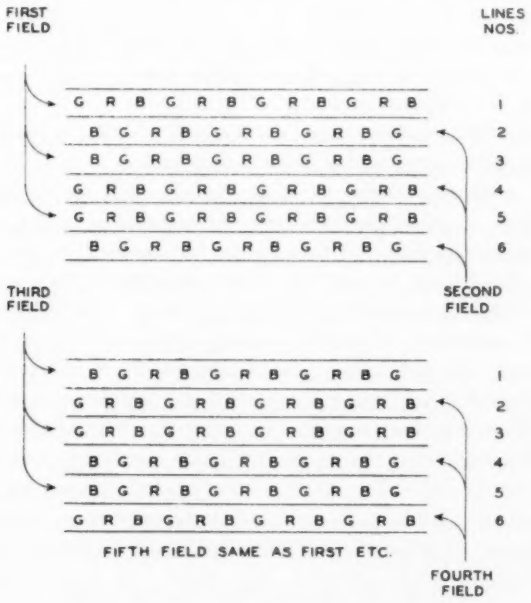

FIRST FIELD
LINES NOS.
G R B G R B G R B G R B 1
B G R B G R B G R B G 2
B G R B G R B G R B G 3
G R B G R B G R B G R B 4
G R B G R B G R B G R B 5
B G R B G R B G R B G 6
THIRD FIELD
SECOND FIELD
B G R B G R B G R B G 1
G R B G R B G R B G R B 2
G R B G R B G R B G R B 3
B G R B G R B G R B G 4
B G R B G R B G R B G 5
G R B G R B G R B G R B 6
FIFTH FIELD SAME AS FIRST ETC.
FOURTH FIELD

Figure 7.

area with three colors with two frames so that 15 complete color pictures are sent in each second. The order in which this is accomplished is shown on Fig. 7.

It is quite apparent that the transmission of color by the RCA system depends on accurate phasing of the sampler in the receiver with respect to the color wave in the transmitted signal. Any phase shift in the sampling oscillator with respect to this color wave will result in false colors being reproduced at the receiver. In its initial demonstrations before the FCC, RCA employed the trailing edge of

the horizontal synchronizing pulse to phase the sampling oscillator in the receiver. This did not appear to provide a sufficiently precise method of timing this circuit inasmuch as the colors during those demonstrations shifted constantly. Since that time, RCA has incorporated a short train of 3.6-megacycle oscillations on the "back porch" of the horizontal blanking pedestal. The receiver sampling oscillator is made to synchronize in frequency and phase with this burst of 3.6 megacycles of energy. With this arrangement any shift in the phase of the color wave due to the circuits through which it must pass will likewise shift the phase of this "burst" of energy and, accordingly, there is no change in the relative phase of the sampling oscillator and the color wave. This device seems to have been quite successful inasmuch as the color stability shown in pictures in later demonstrations was quite good.

As compared with the other two systems, the RCA system is said to be completely compatible with monochrome standards, to have geometric resolution equal to monochrome, and by breaking each line into dots, to avoid the interline flicker problem which is claimed by RCA to be the inherent flaw in the line-sequential method. On the other hand, this system has been criticized for its registration problem (which is present in any all-electronic system), its relative complexity and the fact that the signal cannot be transmitted over a 2.7-megacycle coaxial cable. RCA claims to have removed this last objection by developing a system for sampling the picture at a 2.4-megacycle rate for transmission over the coaxial cable and resampling the output of the cable at the 3.6-megacycle rate for transmission over the air. The RCA system is also claimed by its critics to be more susceptible to noise and interference from other stations than is the case with the other types of color transmission.

THE RCA DIRECT-VIEW COLOR TUBE

It has been quite generally agreed by most engineers who have testified concerning color television systems that, regardless of which system is adopted, the ultimate method of presentation will be a direct-view color tube. It is quite natural then, that the recent demonstration of the RCA color tube was the object of extreme interest on the part of all industry engineers. It was quite generally conceded by all who saw the demonstration that this tube represented a remarkable engineering feat. While the tube, admittedly, has considerable room for improvement, it can definitely be said that a direct-view color tube is in sight for commercial use. To date, the details,

particularly of the manufacture, of this tube have not been divulged by RCA, but a general description can be given.

Of the two types demonstrated, one contains three electron guns and the other only one. In both types, the color screen consists of an array of small, closely spaced phosphor dots arranged in triangular groups, each group containing a green emitting dot, a red emitting dot and a yellow emitting dot. In the tube demonstrated, there were 351,000 dots in all with 117,000 dots for each color. Inasmuch as a good red phosphor has not yet been developed, it is necessary to place a minus yellow-green filter in front of the screen in order to restore proper color balance to the picture.

About one-half inch behind the color screen is placed a metallic mask which contains 117,000 holes or one hole for each of the triangular dot groups. This hole is so positioned with respect to its associated dot group that the difference in the angle of oncoming beam determines the dot which will be excited and consequently which will be seen by the viewer.

In the case of the three-gun tube, the three guns are placed in a bundle as shown in Fig. 4(e) in the neck of the tube with their axes converging at the plane of the metallic screen. Because of the difference in angle at which beams from these three guns will strike the holes, each gun will excite the dots of one color only. Thus, it is necessary only to apply the red signal to one of the guns, the blue signal to another and the green signal to the third in order to provide a color picture. It is quite apparent that this tube could be used not only with the RCA dot-sequential but also with the field-sequential and line-sequential systems.

In the case of the single-tube kinescope, the beam is magnetically displaced, and this displacement is rotated so that, in effect, it occupies in time sequence, the positions of the three guns in the three-gun kinescope. As the beam displacement rotates, the angle at which the beam enters the holes in the perforated screen likewise changes and the different dots are excited in sequence. This tube can likewise be adapted to the dot-, line- or field-sequential systems by rotating the beam displacement at the dot, line or field rates. While the beam is being rotated in this manner, its intensity is modulated in accordance with the amount of color information present in the signal for the particular primary color being transmitted at the moment, this action automatically carrying out the sampling function.

It is apparent that with this tube, there will be 117,000 picture elements in the reproduced picture. This is a reduction in resolu-

tion as compared to what can be obtained in a 4-megacycle bandwidth and one of the lines of development now being pursued by RCA is the construction of a tube with a larger number of picture elements.

SUMMARY

The attempt here has been to distinguish between the three systems on the basis of the color switching rate rather than on the terminal equipment which may have been employed by the three proponents in their demonstrations. This has been done because it is a problem of choosing from among the three color switching rates that is before the Federal Communications Commission in setting engineering standards, rather than the problem of determining which company has developed the best apparatus. Once this decision is made by the FCC, it can be expected that the entire industry will turn to the problem of developing and improving transmitting and receiving equipment for the particular system which has been chosen. Tremendous developments have occurred within the last nine months in the field of color television, and if these continue at their present rate, it can confidently be expected that it will be a commercial reality within a very few years.

ADDENDUM, October 7, 1950

Recent Developments in Color Television

Since the record of the color television proceedings was closed by the FCC, two very interesting alternative systems have been publicly described. These are the frequency interlace system developed by the General Electric Co. and the "Uniplex" system developed by CTI. Neither of these has been tested to date to the extent of constructing complete transmitting and receiving apparatus. However, considerable study has been made of the theoretical aspects of each, and certain critical points have been tested under simulated conditions.

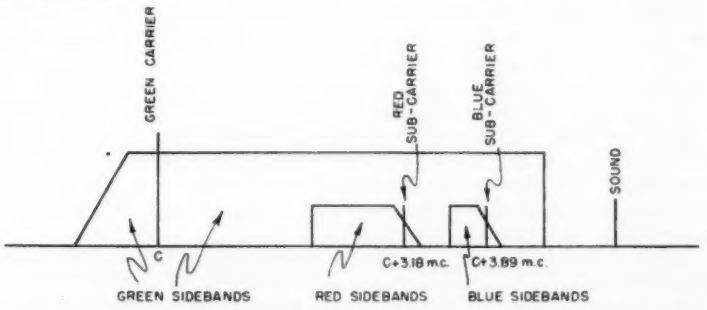
The GE frequency interlace system makes use of the fact that most of the energy in the video waveform is presumed to occur at harmonics of the line frequency of 15,750 cycles/sec. If each line were identical, the energy would be concentrated at these discreet frequencies. Due to the fact that the waveform changes from line to line, the frequency spectrum is spread out somewhat, and as a consequence it is believed by GE that picture information is concentrated in regions of the spectrum lying near the harmonics of the line scanning frequency and occupying about 54% of the total spectrum. Since the other 46% of the spectrum space is not occupied, it is theoretically available for transmission of additional information.

While research has not yet been carried to the extent of determining the best way in which to utilize this unused spectrum space for transmission of

color information, GE has suggested that it might be accomplished in the manner described below.

At the camera the three color signals are produced simultaneously. This could be accomplished, for example, with the RCA color camera. Each signal may contain frequencies extending to 4 megacycles. However, since the higher frequency components in the red and blue signals do not seem to be necessary for the transmission of detail, these signals would be filtered and thereby limit the red bandwidth to 1 megacycle and the blue bandwidth to 0.2 megacycles.

The green bandwidth, being retained to the full 4 megacycles, is considered to be the dominant signal, and it is used to modulate the transmitted carrier using the ordinary vestigial sideband type of transmission. A red subcarrier is then chosen having a frequency such that it will fall midway between two of the sidebands, produced by the green signal. This is accomplished by separating this subcarrier from the green carrier by an odd multiple of one-half the line frequency. One frequency suggested by GE is 3,189,375 cycles/sec which is the 405th multiple of 7,875 cycles/sec. This subcarrier is modulated with video signals from the red channel using a vestigial sideband type of modulation. The red sidebands would then theoretically be interleaved between the green sidebands with very little cross talk between them. A similar method would be used to multiplex the blue subcarrier on the green signal and the blue sidebands would be interleaved between the green in the same manner.



The optimum position of the blue carrier has not been determined. However, one possible arrangement is shown in Fig. 8 which shows the position of the green carrier, the red and blue subcarriers, and the spectral region occupied by the sidebands of each color.

In the color receiver the signal is passed through suitable filters which remove the portions of the spectrum which are not used by the color associated with its particular channel. No attempt is made to remove the interleaved information within this band of frequencies. Mathematical analysis shows that the cross talk which is present due to the presence of these undesired sidebands is 180° out of phase on successive frames so that the net signal over two frames is zero. To the extent to which the persistence of the phosphors and of the eye combines the images of two successive frames, this flicker will not be noticed. The signals accompanying each carrier would be demodulated and would be used to actuate a direct view color tube.

This system is compatible in that the same line field and interlace standards are used as for standard monochrome television. On a black-and-white receiver the green signal would be reproduced. According to GE "Cross talk [from the red and blue sidebands] would cause no trouble because it is geometrically in the same position on the screen as the green signal itself." The red and blue subcarriers would produce a dot pattern which according to GE has been tested and found to be unobjectionable.

The principal advantages claimed for the GE system are compatibility, absence of twinkle, crawl or flicker, and the absence of any precision timing equipment in the receiver. The most serious objection which has been made to the system is the degradation of the picture due to differences in propagation at the three carrier frequencies. The seriousness of this problem can be determined only by field testing.

The Uniplex system described by CTI employs a color switching rate between the dot sequential system of RCA and the line sequential previously advocated by this company. The color repetition rate is 1.008 megacycles which is the 64th harmonic of the line repetition frequency. This is slightly more than one-quarter of the rate at which the colors are switched in the RCA system. Thus the color segments on each line are about four times as long as with the RCA system and it could perhaps be described as a "dash sequential" system. In the transmitted waveform, red, green and blue signals are sent in sequence, the color cycle being completed in approximately 1 μ sec. Mathematical analysis shows that such a waveform will contain very little energy at the third harmonic of 1.008 megacycles but the second and fourth harmonics will be transmitted and will enable reasonably rapid transition from one signal level to another as would be required by varying amounts of primary color in the portion of the picture being transmitted.

An ingenious color camera has been invented by CTI for use in connection with this system. This camera provides the video signal with one image orthicon using a filter printed on 35-mm motion picture film which passes in front of the lens and provides the suitable color separation. The system, however, is not limited to the use of this camera, and the RCA three-tube camera could be adapted to it with ease.

At the receiver the color switching is accomplished by a suitable gating circuit which is synchronized with the color switching at the transmitter by means of low-amplitude 3.024-megacycle signal which is transmitted continually. This signal is 180° out of phase on successive frames and to an extent is canceled out by the persistence of the phosphor and the eye. Color phasing is accomplished by transmitting a burst of energy at 1.008 megacycles during a portion of the vertical blanking period. The demodulated signal is gated in synchronism with the transmitter for separation of the three colors and the three signals are then applied to the picture reproducing device whatever it may be. It is felt that in all probability this will be a direct-view color tube.

The principal advantages claimed for this system are compatibility, a minimum amount of color contamination due to color cross talk, and considerably simplified apparatus. Simulated tests are said to have shown that small area flicker with this system would be no more serious than the RCA system even though the dots are somewhat longer.

Color Cathode-Ray Tube With Three Phosphor Bands

By CONSTANTIN S. SZEGHO

The Rauland Corp., Chicago, Ill.

SUMMARY: A cathode-ray tube with a screen consisting of three phosphor bands fluorescing in the primary colors of red, blue and green may, in principle, be used to effect wholly electronic reproduction of television pictures in natural color if field- or line-sequential transmitting norms are employed. However, this tube inherently suffers from two limitations: the screen area is inefficiently utilized from the standpoint of light output, and the resolution capabilities are inadequate.

Color television pictures transmitted by field- or line-sequential systems can be reproduced by a cathode-ray tube in a way which somewhat resembles the well-known Thomascolor system of color cinematography.[1] In the latter a scene is recorded on different parts of a film through primary color filters, for example, Wratten filters Nos. 26, 47 and 58. If the resulting black-and-white film images are projected through the same filters by a parallax-free optical system and superimposed, a picture in natural colors results. In a color television system, a corresponding series of black-and-white images, containing the light and shade values for the three primary colors, appear on different parts of the screen of a cathode-ray tube, having only one gun and one deflection system.[2] Primary color filters may be placed in front of the image sections of the tube and the color images derived therefrom are superimposed on a viewing screen by a suitable projection-optical system. Scanning of the three image areas of the tube screen may be in accordance with any of several well-understood processes. For example, with field-sequential transmission the individual areas are completely scanned in sequence and it is convenient to arrange the image areas one below the other. With line-sequential transmission, individual lines of the image areas are scanned in a repeating sequence and it is preferable to have these areas in side-by-side relation. The choice of the image-area orientation, the number of fields per second, the manner of interlace, etc., are dictated by the specifications of the color television system itself and will not be considered further. It is sufficient to note that in any case the color system is wholly electronic without any mechanical moving parts. Of course, since primary color images are superposed optically,

Presented: April 25, 1950, at the SMPTE Convention in Chicago.

it is strictly a projection system and is not applicable to direct-view television. Moreover, as the picture tube has only one gun, it is not suitable for use with simultaneous color transmissions and the provision of discretely different image areas further limits the practical utility of the tube to systems of the field- and line-sequential scanning type because, in order to reproduce images transmitted by a dot sequential system, the spot would have to fly between picture points located in each of the three separate image areas which is not practically realizable. Other limitations, such as stringent requirements for linear scanning to insure registry of the three images, and matters of field or line flicker and line crawl, and the associated issue of compatibility with black-and-white transmissions will not be dealt with. The remainder of this paper is concerned only with the reproducing cathode-ray tube itself.

Fluorescent Screen

The Wratten filters mentioned above have an average light transmission of only about 15%, so that approximately 85% of the light is wasted. As the color system is of the projection type which inevitably involves a considerable light loss in the optical system used for superimposing the primary color images, the additional absorption in the filters is a material drawback. Therefore, the first step in the development of a new color tube for use in the system was to dispense with these filters. A cathode-ray tube was constructed having three image areas capable of fluorescing in the three primary colors in response to electron bombardment. Specifically, the screen consisted of three phosphor bands: a blue band of zinc sulfide activated with silver, a green band of zinc orthosilicate activated with manganese and a red fluorescing band of zinc cadmium sulfide activated with silver. The spectral distribution curves of these phosphors, as manufactured by Patterson Screen Division of E. I. du Pont de Nemours & Co., are shown in Fig. 1. In making the measurements for these curves, the phosphors were excited by ultraviolet light instead of cathode rays, but it is felt that this did not change their spectral distribution materially. Trichromatic coefficients (x and y), dominant wavelength and purity are given in Table I. Characteristic curves have been given for two red powders which were used in different tubes, and it may be seen from Fig. 1, where the cutoff of Wratten filter No. 26 is also shown, that a substantial portion of the energy of these phosphors falls in the unwanted orange region. It is possible that cadmium phosphates or borates would have more suitable spectral distribution, but they were not tried.

TABLE I. Characteristics of the Phosphors

No. (Patterson)	Q-20-1055	Q-36-1080	Q-37-1243	608
Material	ZnS	ZnCdS	ZnCdS	Willemite
Excitation	3650 A	3650 A	3650 A	2537 A
x	.156	.557	.602	.209
y	.084	.417	.357	.745
Dominant wavelength, mμ	467	590	602.5	536
% Purity	86	93	89	93

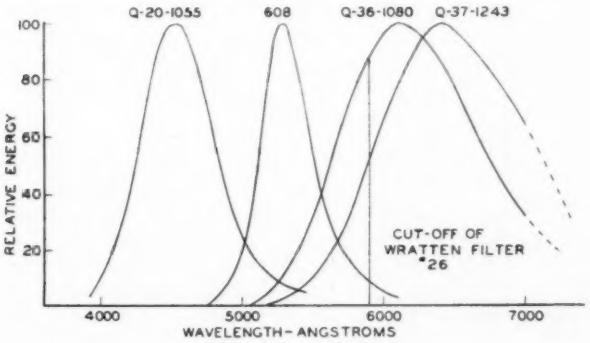


Fig. 1. Spectral energy distribution of the phosphors.

Experimental tubes with 7- and 10-in. diameter screens were made, the middle phosphor bands being approximately 1⅞ in. and 2¾ in. wide, respectively. Two methods of screen application were tried and they will be described with reference to the apparatus shown in Fig. 2. In the first method, illustrated by the diagrams at the right of the figure, the cylindrical part of the tube envelope is cut open approximately 4 in. from the screen and a mask, comprising one or more stainless-steel sheet segments, is placed on the glass to cover approximately two-thirds of the screen area. The blue band is now settled by the customary settling technique on the remaining and exposed one-third area of the screen. Thereafter, the settling liquid is siphoned out, and the screen section is baked. The mask may then be inverted, covering the screen section already deposited, and exposing another section on which another phosphor material is settled and dried. In the next step, the mask is arranged to cover the two coated screen sections, leaving the third to receive a third phosphor in a similar manner. This is a laborious process, and the repeated moistening and drying steps may reduce the efficiency of the fluorescent bands.

In the second method employed, a settling chamber having three compartments made watertight with latex rubber, was used. If the same hydrostatic pressure is maintained in each compartment, the three screens may be settled simultaneously without seepage, and only one drying process is necessary. After the three-section fluores-

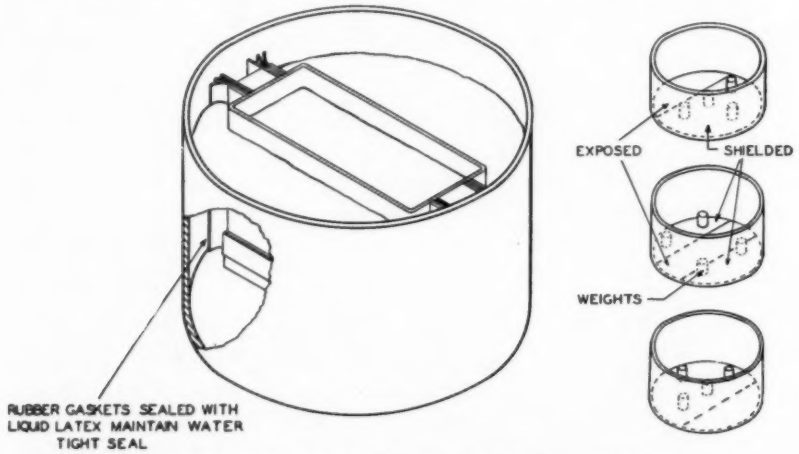


Fig. 2. Masks used in the preparation of the fluorescent screen.

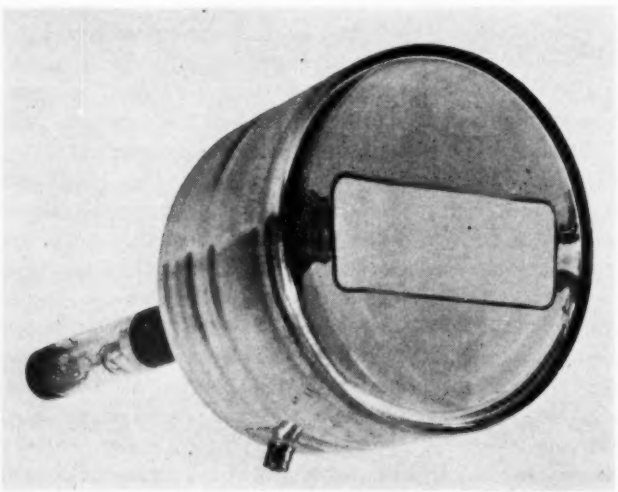


Fig. 3. View of 7-in. cathode-ray tube with three phosphor bands.

cent screen has been fabricated by whatever method chosen, the screen-bearing portion of the tube envelope is rejoined to the rest of the glass bulb, and the screen is aluminized, using the customary organic film basing and aluminum evaporation techniques. This aluminum backing removes the sticking potential that may otherwise be encountered in the operation of the tube and nearly doubles the brightness by functioning as a reflecting mirror. Figure 3 is a photograph of the completed screen, showing an approximately $\frac{1}{8}$-in. wide gap between the color bands which is permissible as the beam is blanked out when scanning of these gaps would occur.

Consideration will now be given to the light output of such a banded screen. The area of one color image is approximately one-

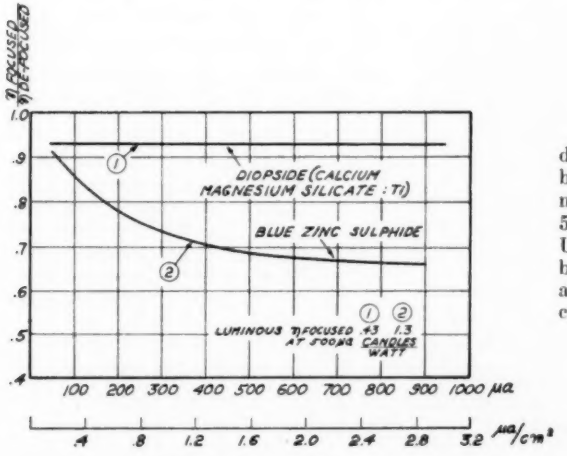


Fig. 4. Beam current density saturation of blue phosphors; aluminum backed, 25-kv, 525 lines, 30 frames. Upper abscissa scale: beam current; lower abscissa scale: raster current density.

ninth of the entire raster area of the tube. This means that only one-ninth of the light flux which could be made available, is utilized. The situation is even less favorable when saturation phenomena of the phosphors are taken into account. It is found that the zinc sulfide and zinc cadmium sulfide types of phosphors saturate considerably at the high current densities prescribed by the spot size necessitated by the small area of one color image. Their luminous efficiency drops at high beam current densities, as shown on Fig. 4 where the ratio of the luminous efficiency of a focused raster relative to a de-focused raster of a blue zinc sulfide is plotted in terms of the beam current. The luminous efficiency η was measured in candles per watt. The cross-sectional area of the de-focused spot was twice that of the focused spot and the focused spot–current density measured at 400 μa

(microamperes) had the high value of approximately ½ amp/sq cm. The corresponding raster-current density was relatively low as may be seen by reference to the lower abscissa scale of the figure. It is true that a nonsaturating blue phosphor, a calcium magnesium silicate, is available and its saturation characteristic is also shown on the figure, but this material is not very efficient, having a luminous efficiency at high-current densities of only about one-third that of the zinc sulfide. Consequently, its use would not improve light output. The green phosphor is also a silicate and saturates, although to a lesser extent than the blue and red phosphors used in making the tube.

In view of the small size of each color image the raster-current density of the tube is unusually large and, since the heat cannot be

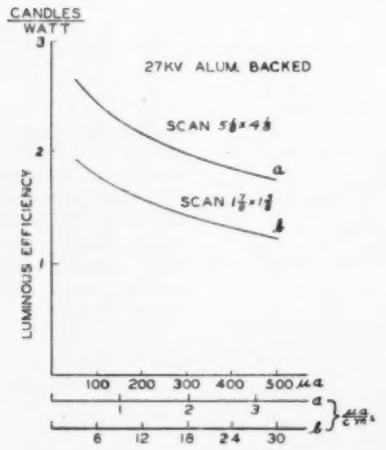


Fig. 5. Luminous efficiency of blue ZnS at two different raster current densities; aluminum backed, 27-kv, 525 lines, 30 frames. Upper abscissa scale: beam current; lower abscissa scales: raster current density.

adequately dissipated, the screen heats up. This is most undesirable because certain zinc sulfides lose luminous efficiency at elevated temperatures. This is shown in Fig. 5, where the luminous efficiency for a scanned area of 5⅝ × 4⅛ in. is compared with that obtained in scanning an area nine times smaller. Of course, for sequential systems having lower field-scan rates per second, the drop would not be as pronounced because the temperature rise would be less.

Again, as a direct consequence of the high raster density or high screen loading, the fluorescent powders darken, an effect known as electron burning. When this occurs, the screen brightness drops 15–40% in a few hours of operation, and then remains essentially constant at that level. Another cause for diminished brightness is discoloration of the screen supporting glass resulting from X rays

released at 30 kv, which is the working voltage of this tube. Loss of brightness attributable to discoloration of the glass may be minimized by use of the new, nonburning glass No. 3459 of the Pittsburgh Plate Glass Co., instead of pyrex glass from which the first tubes were made.

Surface brightness of the green phosphor was measured after a few hours of operation and found to be approximately 7000 ft-L at 400-μa beam current and $1\frac{7}{8} \times 1\frac{3}{8}$ in. raster, 525 lines, 30 frames. Corresponding figures for the blue and red phosphors were approximately 1700 ft-L and 1400 ft-L, respectively. With this brightness of the primary image areas, the highlight brightness of a colored picture on a 12 × 16 in. uniformly diffusing screen is in the order of 4.5 ft-L, if an optical system having a light-gathering efficiency of 10% is assumed and the Color Television Inc. transmitting norm is used.

While saturation limitations may one day be overcome by new and better phosphors, improvement of light loss due to insufficient utilization of the screen area may be visualized by scanning primary areas that are larger and give more light even though their aspect ratio is incorrect, so long as appropriate cylindrical lens elements are also used to gather light from the whole of the scanned area and project an image having the correct aspect ratio.

Resolution

The postage-stamp size of each color image imposes exacting resolution requirements, which are inherently impossible to meet with the present three-band tube. Approximately 475 lines must be resolved in each picture, a resolution of 12 lines per millimeter. Moreover, while one color-image area is approximately in the center of the screen, the other two are toward the edges, and excessive deflection de-focusing cannot be tolerated. Unfortunately, a small spot size in the center and minimum de-focusing toward the edges of a screen are contradicting requirements from the point of view of tube design.

A satisfactory prototype for a projection tube which has the required resolution on a small screen, corresponding to the central color area of the 3-band tube, does exist and has been described, for example, by H. Rinia, J. deGier and P. M. Van Alphen.[3] The outline of such a tube is drawn at the top of Fig. 6, which also shows below schematically the geometry of the scaled-up models for two 3-band tubes having screen diameters of 7 in.

In the three color-band tube under consideration it is necessary to scan a distance in either the line or field direction equal to three times the corresponding dimension of one color area. In order to scan all

three primary-image areas, two possibilities suggest themselves if it is required to maintain the same deflection angle α which was required, because it was desired to operate this tube with deflection equipment available for 5TP4 projection tubes having a deflection angle of 50°. Using the notations of Fig. 6, the Helmholtz-Lagrange law defines the spot size in the center of the screen as follows:

$$y_{2(\text{center})} = \frac{\phi}{\theta}\sqrt{\frac{E_1}{E_2}}y_1$$

where $y_{2(\text{center})}$ is the radius of spot at the center of screen;
ϕ semi-divergence-angle of the beam at the cathode side;
θ semi-convergence-angle of the beam at the screen side;
E_1 emission energy in electron volts;
E_2 anode voltage; and
y_1 radius of beam at crossover point.

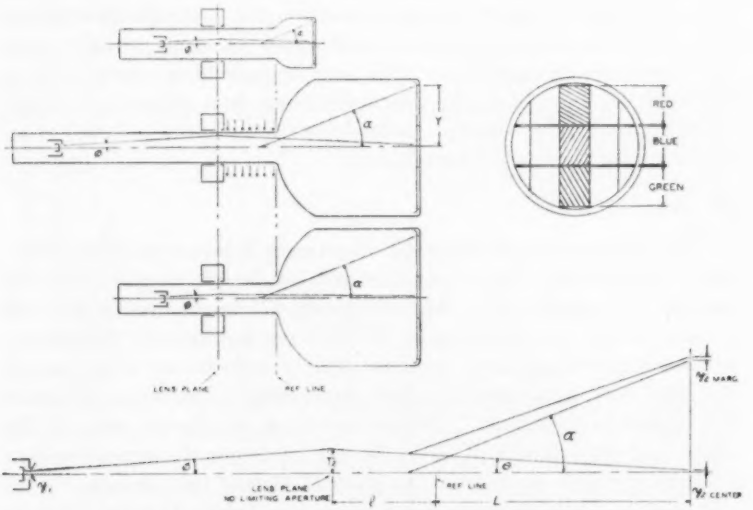


Fig. 6. Schematic of 7-in., three phosphor band projection tube.

If it is assumed that the electrical conditions for the tube are to remain constant, the center spot size varies inversely with the angle θ:

$$y_{2(\text{center})} \sim \frac{1}{\theta}$$

The formula expressing increase of spot radius in terms of beam deflection is[4]:

$$y_{2(\text{margin})} = \frac{3Y^2 r_l}{2\left(L + \frac{l}{2}\right)^2}$$

where $y_{2(\text{margin})}$ is the spot radius near the edge of the screen;
Y half of the total deflection on the screen;
r_l beam radius in the lens plane which is approximately equal to the beam radius in the deflection field;
l length of deflection field; and
L distance from the end of deflection field to screen.

From the geometry of the arrangement, it is seen that

$$\frac{Y}{L + \frac{l}{2}} \approx \tan \alpha$$

where α is the deflection angle.
For constant deflection angle α:

$$y_{2(\text{margin})} \sim r_l .$$

Table II gives the beam radius at the lens and the convergence angle at the screen for the three cases illustrated in the figure and in the order recited, namely, the prototype tube with but a single small screen, the first mentioned scaled-up model and the last mentioned scaled-up model.

TABLE II

Case	Beam radius at lens	Convergence angle at screen
1	r_l	$\frac{3r_l}{3l + L} \approx \theta$
2	$3r_l$	$\frac{3r_l}{l + L} \approx \theta$
3	r_l	$\frac{r_l}{l + L} \approx \frac{\theta}{3}$

In Case 2 the center-spot size, determined by the reciprocal of the convergence angle, remains small as desired because θ remains approximately the same as in the prototype, but the marginal-spot size, determined by the beam radius at the lens, becomes larger because this radius increases threefold. In case 3 the convergence angle becomes too small and the center-spot size increases undesirably even though the marginal-spot size is maintained at substantially the desired value. It is manifest that at best a compromise solution

must be accepted for it is not apparently possible to scan all three primary-image areas while preserving the resolution at both the center and marginal portions of the screen.

Suitability for Theater Television

The question which must be in the minds of motion picture engineers—whether or not this tube may ultimately be used for color television projection in theater installations—has been answered in the foregoing analysis. The light requirements for large screen work are increased manifoldly, at least 100 times for a 15 × 20 ft picture. The poor utilization of the screen area for light output rules out the three-band cathode-ray tube for this service. For monochrome theater television, a cathode-ray tube having a minimum of 10-in. diameter and a fast Schmidt optical system are presently required, and it is the opinion of the author that if the complication of three optical systems to superimpose primary-color images is to be added, it would be more advantageous to make use of three cathode-ray tubes and simultaneous color transmissions. Local conversion of the sequential information for simultaneous modulation of three guns with the aid of storage tubes could also be visualized. This would increase light output by a factor of 27 and be of material help in overcoming the greatest hurdle of theatre projection: insufficient light output.

Acknowledgment: The author is greatly indebted to Dr. E. Meschter of the Patterson Screen Div., E. I. du Pont de Nemours & Co., for the spectral distribution measurements.

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A Magnetic Record-Reproduce Head

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SUMMARY: It is the purpose of this paper to discuss various features of a combination magnetic record-reproduce head of the ring-shaped type, known as MI-10794, with emphasis more on the general principles of construction than details of assembly. Shown in the paper are various lamination shapes for ring-type heads; the change of head inductance with change of front-gap and back-gap spacer thickness; the lamination stacking factor as a function of lamination thickness; the shape of the lamination employed for the subject head; flux distribution patterns about the front-gap of a record head for various thicknesses of front-gap spacer; the "gap effect" of a reproduce head; the output voltage and inductance of a reproduce head as a function of the front-gap reluctance; and a photograph of the finished record-reproduce head.

RING-SHAPED magnetic record and reproduce heads were first described in 1935 in a paper by E. Schuller.[1] The term ring-shaped heads does not refer specifically to circular cores, but includes rectangular, semicircular, diamond, trapezoidal, and even triangular shapes, as shown in Fig. 1. In general, therefore, a ring-shaped magnetic record or reproduce head may be defined as one in which the magnetic material forms a quasi-toroidal enclosure with one or more air gaps, and with the magnetic medium bridging one of these gaps, commonly spoken of as the front-gap, and contacting the structure on one side only.

When a second gap is inserted in the core so as to divide it into two symmetrical halves, the second interstice may be termed the back-gap. Each hiatus usually contains a nonmagnetic spacer, the "front" and "back" spacer, although some commercial ringheads have butt joints. One or more coils may be wound around the core, and the entire assembly is usually placed in a high-permeability can to act as a magnetic shield. It is the purpose of the following to discuss various features of one such head, known in RCA as the MI-10794 combination magnetic record-reproduce head, with emphasis more on general principles of construction than details of assembly.

Head Inductance

The inductance of the head varies with the thickness of both the

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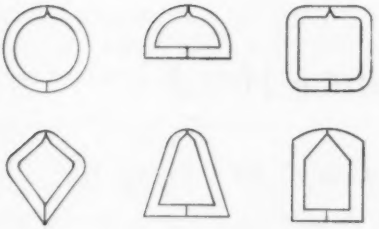

Fig. 1. Core shapes for magnetic heads.

front- and the back-gap spacers, and is given approximately by the equation

$$L = \frac{KN^2}{r + R}$$

where r = reluctance of front-gap;

$$= \frac{l}{wd}$$

l = gap-length, cm,
d = gap-width, cm,
w = gap-depth, cm,
R = reluctance of back-gap;

$$= \frac{l_o}{w_o d_o}$$

l_o = gap-length, cm,
w_o = gap-width, cm,
d_o = gap-depth, cm,
N = number of turns,
K = constant.

The above equation is true as long as the reluctance of the core material is small compared to the reluctances of the gaps; otherwise, an additional term for the core reluctance must be introduced in the denominator of the above equation. Figure 2 shows the variation of inductance with thickness of front- and back-gap spacers; these curves, calculated by the above equation, correspond closely with observed values.

Magnetic record heads of the ring-shaped core type are usually constructed with a low-impedance winding, and reproduce heads, with a high-impedance winding. The reason for the low impedance of a record head lies in the fact that the line to the head has a certain amount of capacity, which represents a leakage path for the high-frequency-bias current which is almost always used. If the record head had a high inductance, the line leakage would constitute a con-

siderable loss. In the case of the reproduce head, where no bias frequency is employed, a high-impedance winding on the head is satisfactory, provided the length of the cable connecting the head with the reproduce preamplifier is short and otherwise is so constructed as to have a low leakage capacity, otherwise high-frequency signal losses may be suffered.

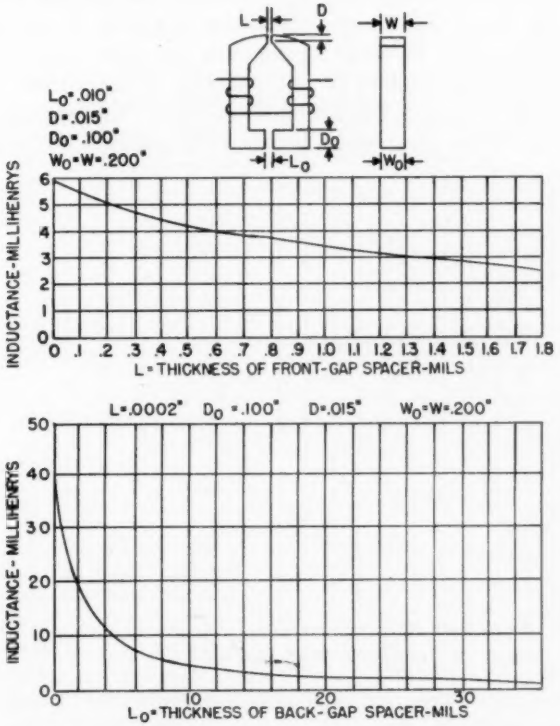

Fig. 2. Upper part of figure shows variation of head inductance with thickness of front-gap spacer. Lower part of figure shows variation of head inductance with thickness of back-gap spacer.

For the head under consideration, which can be used either as a record or as a reproduce head, the inductance is 5 mh (millihenrys). This means, essentially, that a step-up transformer with a high turns ratio is required in the associated amplifier when the unit is employed as a reproduce head. As such, the combination is equivalent to a reproduce head with a 2-h(henry) inductance, which, of course, represents a head of impractical construction. Therefore,

since for maximum voltage on the first tube grid of the reproducing amplifier a step-up transformer is still necessary with heads of feasible or practicable inductances, a reproduce head with a 5-mh inductance does not appear to present difficulties or complications.

Besides the number of turns on the winding and the thicknesses of the front- and back-gap spacers, the inductance of the head is determined by the lamination material and the number of laminations in the core. Extremely thin laminations, say 2 mils thick, to reduce eddy current losses to a minimum, are difficult to handle and exhibit a low stacking factor. By stacking factor is meant the per cent space occupied by the laminations themselves, exclusive of the space taken up by the cement between the laminations. As an example, consider a core 200 mils wide, containing 80 two-mil laminations held together by 79 layers of cement each 0.5 mil thick. In this case the space factor would be 80%. When 6-mil laminations are used, held together by layers of cement each 0.5 mil thick, the actual space taken up by the laminations in the 200-mil-wide core comes to 92%. Figure 3 shows the space factor as a function of lamination thickness for a 200-mil core. Thicker laminations mean not only that fewer turns of wire will be required to obtain the desired inductance, but also that the flux density in the laminations will be less, because the space factor is greater, thereby reducing possible distortion in the head at high audio and bias currents.

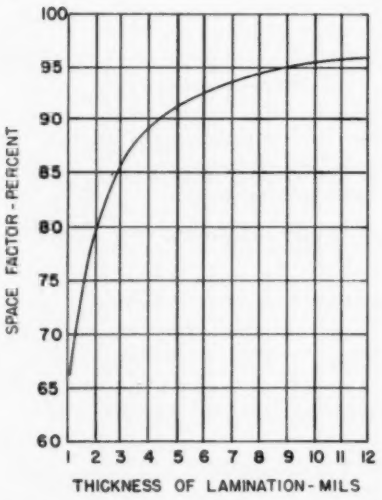

Fig. 3. Variation of space or stacking factor of magnetic head core with lamination thickness.

Figure 4 shows the approximate shape of the lamination used.

FRONT-GAP

In the case of the record head, the front-gap exists for the purpose of providing a leakage flux path for magnetizing the magnetic tape as it passes over the head in recording. Concerning the reproduce head, if no front-gap reluctance existed, the flux from the tape would merely pass through the pole tips and not through that part of the core on which the coil is wound and in which it is desired to induce an electromotive force.

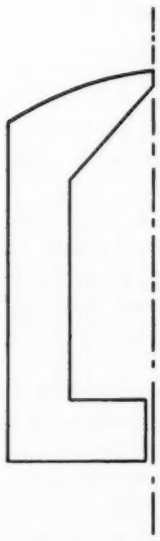

Fig. 4. Approximate shape of lamination used in subject magnetic head.

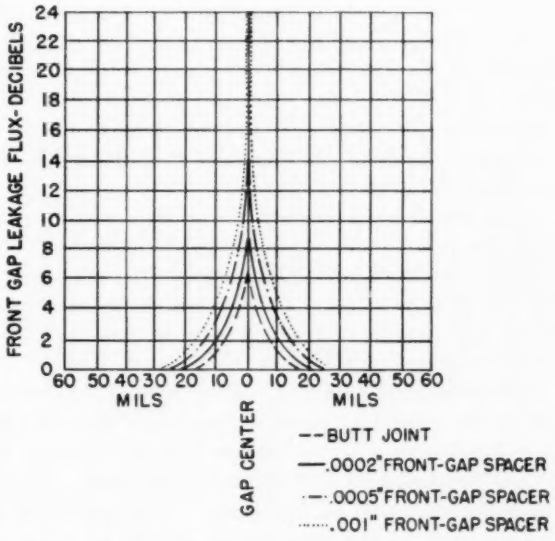

Fig. 5. Leakage flux distribution about front-gap of a ring-type magnetic record head, in the absence of a recording medium, when spacers of different thicknesses are inserted in the gap while constant current is supplied to the head.

Figure 5 shows leakage path distributions about the front-gap of a ring-type magnetic record head, in the absence of a recording medium, when spacers of different thicknesses are inserted in the gap while constant current is supplied to the head. The spacer serves the double purpose of maintaining the nonmagnetic gap parallel and to avoid the accumulation of ferrous dirt which would change the performance of the head. The curves were obtained by moving the head past a single loop of No. 46 wire. The head was fastened to a brass rack, and the pinion for the rack was driven by the curve

recorder; in this manner a measure of the flux density with respect to the distance traversed by the head was secured on the curve paper. The greater leakage flux with increasing thickness of front-gap spacer, or increased front-gap reluctance, is clearly evident.

It should be noted again that the curves were obtained without a magnetic medium over the gap. Hence, they are useful chiefly for comparing heads and do not necessarily show the actual leakage flux distribution when the head is in operation; that is, when magnetic tape is lying on the head or when it is passing over it.

In an RCA standard head, the front-gap spacer consists of a very hard nonmagnetic alloy. This alloy is considerably harder than the lamination material, and hence prevents the forming of burrs on the pole tips. These burrs tend to short-circuit the gap, and to alter the head performance. To prevent the accumulation of electrostatic charges on the head, the spacer is grounded to the mumetal housing, as is the cable shield.

After the head is assembled, the tape-bearing surface of the cores must be polished to secure proper scanning. This is obtained by lapping the head with successively finer aluminum oxide or silicon carbide papers in a jig to give the required contour on the head. Final polishing leaves a well-defined gap, free of bridging burrs, when examined with a 500× microscope.

For obtaining sufficient high-frequency response, particularly as far as the reproduce head is concerned, the "length" of this gap is very important. As far back as 1935, E. Schuller, in the paper cited at the beginning of the article, noted that "the magnitude of this magnetic gap, that is, the extent of the recording magnetic field in the direction of the tape travel, should be approximately one-fifth of the smallest half-wave length." This criterion is more applicable to d-c biasing, however, than to a-c biasing, according to S. J. Begun,[2] who writes that "when a-c bias is employed, the effect of the length of the recording gap is practically negligible when the recording field is uniform and sharply defined." Hence, by employing for the record head a thinner than necessary front-gap spacer, namely, the spacer required for the reproduce head (see below), some loss in sensitivity is incurred, as may be seen from Fig. 5.

Schott[3] has determined that the output of a reproduce head varies as

$$20 \log \frac{\sin \frac{\pi d}{\lambda}}{\frac{\pi d}{\lambda}}$$

where d = *effective* gap-length,
λ = recorded wavelength.

The physical gap-length, however, is not equal to the effective gap-length, the latter being from 10 to 50% larger. Figure 6 shows the "gap-effect," as calculated by the above equation.

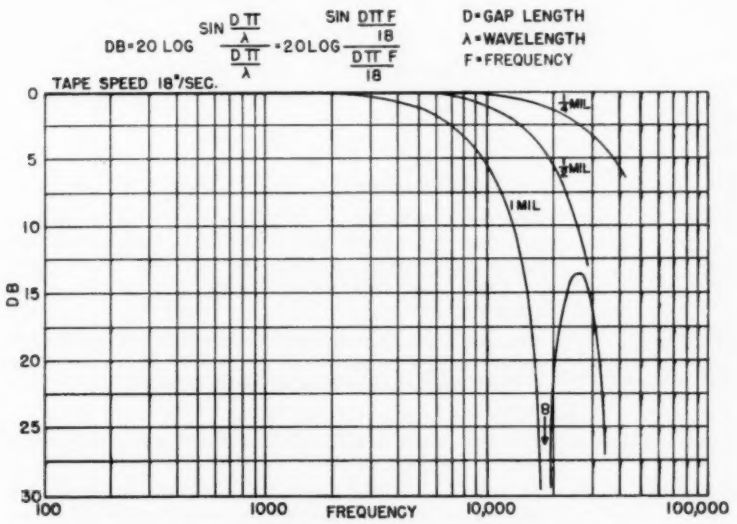

Fig. 6. Figure shows "gap effect" of a reproduce head, or variation of reproduce head output with frequency for various front-gap spacers.

BACK-GAP

A back-gap is frequently introduced in ring magnetic record and reproduce heads to reduce d-c magnetization with a consequent lowering of the noise produced by such magnetization. This is effected by "shearing" the hysteresis curve of the lamination material, as shown in Fig. 7. When the d-c magnetizing force in a closed ferrous ring is reduced to zero, the ring will have a residual induction as indicated by the point A in the figure. When a large back-gap is inserted in the toroid, however, a "shearing" of the hysteresis curve is effected, and the remanent induction, B, becomes rather small.

It may now be desirable to point out significant differences between record heads and reproduce heads for a better understanding of these transducers.

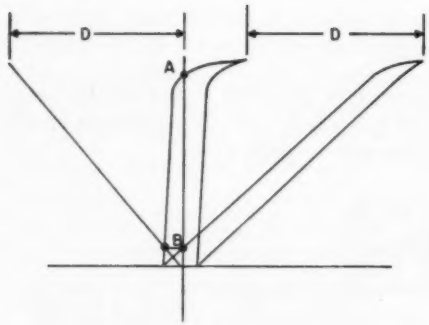

Fig. 7. Figure shows effect of "shearing" the hysteresis loop of the magnetic record head lamination material.

	Record Head	Reproduce Head
Head resonance	Frequency of resonance, determined by head inductance and leakage capacity, should be higher than bias-current frequency.	Frequency of resonance should be higher than highest frequency to be reproduced.
Shielding	Relatively unimportant, because field generated by head is much greater than external fields.	Very important because field generated by recorded medium is small.
Recording field	Effective gap-length is, within limits, not critical.	Effective gap-length should be as small as possible.
Magnetic material	Should show low eddy-current and hysteresis losses, to prevent heating and magnetic saturation at bias-current frequency.	Heating and magnetic saturation are unlikely to occur.
Impedance	Should not be high, to prevent bias-current losses in head and leads to head by leakage capacity.	Not critical.
Size	Within limits, not critical.	Should be small to reduce hum pickup.

The preceding is concerned chiefly with a delineation of the significant characteristics, both in performance and construction, of magnetic record and reproduce heads. The following presents a mathematical analysis of these units, more from the point of view of design considerations than from the standpoint of circumscribing their operational behavior.

The action of a reproduce head may be explained by means of Fig. 8. Assuming the tape to be a constant flux (high reluctance) generator providing a flux ϕ_a, we have across the tape head:

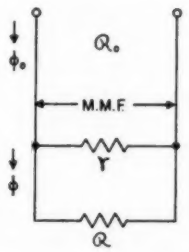

Fig. 8. Magnetic schematic of a reproduce head.

$$\text{Magneto-motive force} = \phi_o R_o$$

$$= \phi_o \frac{rR}{r + R}$$

$$= \phi R$$

$$\phi = \phi_o \frac{r}{r + R}$$

where ϕ = flux through the core
r = reluctance of front-gap
R = reluctance of rear-gap plus core reluctance

The voltage generated in the coil of the reproduce head will be

$$E = N \frac{d\phi}{dt} = N \frac{d\phi_o}{dt} \frac{r}{r + R}$$

$$= \frac{KNr}{r + R}$$

A measure of the reproduce head efficiency is given by*

$$Q' = \frac{E^2}{L} = \frac{\left(\frac{K_1 N r}{r + R}\right)^2}{\frac{K_2 N^2}{r + R}}$$

$$= \frac{K_3 r^2}{r + R}$$

where, as before, r = front-gap reluctance
R = back-gap reluctance
K_1, K_2, K_3 = constants
N = number of turns
L = inductance of reproduce head
E = output voltage of reproduce head

* Advanced by L. J. Anderson, Radio Corporation of America, RCA Victor Div., Camden, N. J.

If in the above equation we set $R = ar$, we get

$$Q' = \frac{K_3 r}{1 + a}$$

If r is held constant, the efficiency is proportional to $1/(1 + a)$; see Fig. 8A.

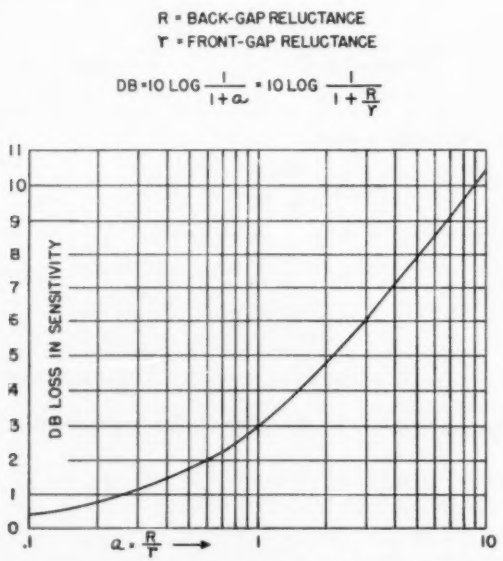

Fig. 8A. Loss in decibels, in reproduce head sensitivity as the back-gap spacer is made thicker while maintaining constant head inductance and front-gap reluctance.

The voltages of two reproduce heads of similar construction and equal number of turns are related as follows:

$$\frac{E_1}{E_2} = \frac{r_1(r_2 + R_2)}{r_2(r_1 + R_1)}$$

$$\text{or db} = 20 \log \frac{E_1}{E_2} = 20 \log \frac{r_1}{r_2} \frac{(r_2 + R_2)}{(r_1 + R_1)}$$

where r_1, r_2 = front-gap reluctances of heads 1 and 2 respectively,
R_1, R_2 = back-gap reluctances of heads 1 and 2 respectively,
E_1, E_2 = output voltages of heads 1 and 2 respectively.

If we now make the following substitutions

$$r_1 = ar_2$$
$$R_1 = R_2 = R$$
$$R = br_2$$

the above equation can be written: $\text{db} = 20 \log \dfrac{a(1 + b)}{a + b}$

It is seen (Fig. 9) that an increased reluctance at the front-gap (as when wear on the head reduces the pole face depth, d, in Fig. 2) increases the output voltage from a reproduce head. This increase in the voltage is to some extent dependent on the reluctance of the back-gap. In Fig. 9 the abscissa represents the factor by which the reluctance of the rear-gap is larger than that of the front-gap, and in which the ordinates show the gain in output in decibels resulting from increasing the front-gap reluctance by the factor a. For example, a head having a rear-gap reluctance equal to the front-gap reluctance ($b = 1$) will provide a 2.6-db gain in output when its front-gap re-

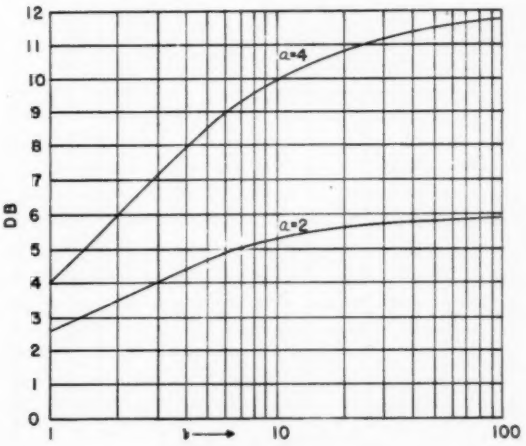

Fig. 9. Variation of magnetic reproduce head output with ratio of rear-gap to front-gap reluctance for two kinds of head.

luctance is doubled ($a = 2$), as when wear on the head has reduced the pole face depth, d, to one-half its former dimension; a head having a rear-gap reluctance which is ten times as great as the front-gap reluctance ($b = 10$) will provide a 5.3-db gain in output when its front-gap reluctance is doubled ($a = 2$), as when wear on the head has reduced the pole face depth, d, to one-half its former dimension.

Whenever wear on top of the head increases the front-gap reluctance, a decrease in the inductance occurs. This variation in inductance is given by

$$\frac{L}{L^1} = \frac{r^1 + R}{r + R}$$

where L = inductance of head when head was first put in operation,
L^1 = inductance of head after wear on top of head has increased its front-gap reluctance,
r = front-gap reluctance when head was first put in operation,
r^1 = front-gap reluctance after wear on top of head has decreased the pole face depth, d,
R = rear-gap reluctance.

In Fig. 10, the abscissa represents the pole face depth in mils and the ordinates indicate the inductance and the gain in output voltage in decibels from a reproduce head as the top of the head becomes worn.

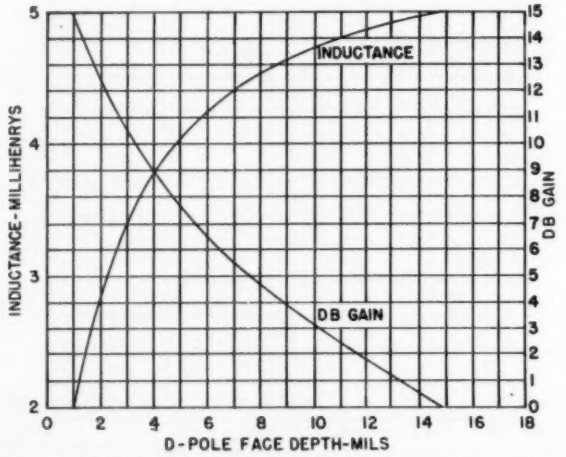

Fig. 10. Variation of reproduce head inductance and reproduce head output with pole face depth of front-gap.

Assuming the initial pole face depth to be 15 mils, then the inductance of the head is 5 mh. When wear on the head has reduced the depth to 5 mils, the inductance has decreased to 4 mh while the output voltage from the head has increased 7.5 db. If the front-gap is truly a rectangular parallelepiped, so that the gap does not become wider with decreasing pole face depth, the frequency response will remain relatively unaffected even though the sensitivity increases.

CONSTRUCTION

The core assembly is embedded in plastic which, at the same time, acts as the bonding agent between the two telescoping high-permeability cans which comprise the housing for the head. The plastic

has a dielectric constant of 3.7 at 50 cycles and 3.6 at 1 megacycle, at 22 C, which is practically equivalent to that of quartz.

The fact that the cores are not clamped mechanically, always an undesirable condition for permalloy laminated structures, but are embedded in a substance of greatly different mechanical impedance than the metal housing, makes the head singularly free of microphonics.

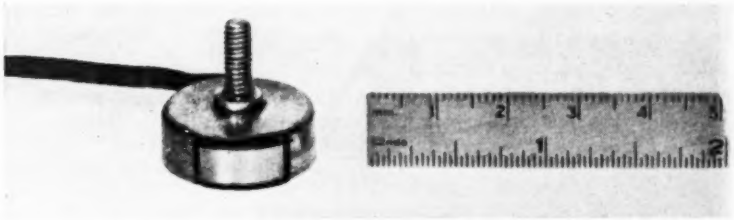

Fig. 11. Photograph of MI–10795 magnetic record-reproduce head.

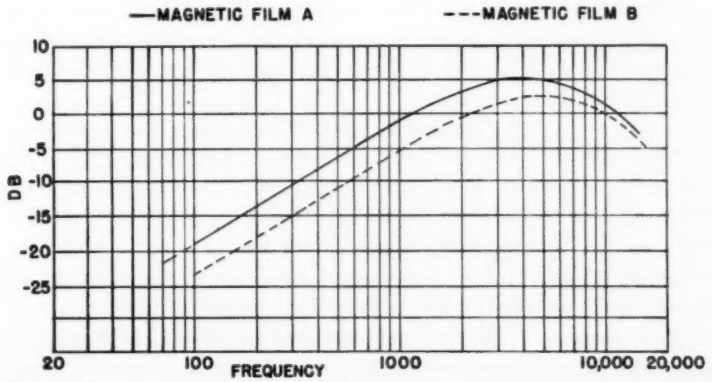

Fig. 12. Combination of subject head response and magnetic film characteristic for two types of film when constant current is supplied to the record head and the recording is reproduced on the same head.

Figure 11 shows a photograph of the completed head. The 18-8 stainless steel stud, shot-welded to one of the mumetal cans, is used for fastening the unit to the ball of a ball-and-socket type of mounting which allows longitudinal, lateral and transverse adjustments[4] of the head.

Figure 12 shows the combination of head response and film characteristic for magnetic film A and magnetic film B, when constant

current is supplied to the record head and the recording is reproduced on the same head and measured with a high-impedance vacuum tube voltmeter. The 68-kc bias current for the measurement was .016 ma; the signal current, 2 ma; the film speed, 18 in./sec; and the output voltage (in the case of the A film) at the peak frequency for 100% modulated track,* 2 mv. Since demagnetization effects on the film are not readily dissociable from gap effects, Fig. 12 does not represent the frequency response of the head; it does still, however, serve as a valuable criterion for the head response to those familiar or experienced with the subject.

The head is 7/8 in. in diameter, and thin enough so that three heads, without studs, can be mounted in a line to produce, on 35-mm magnetic film, a triple track with each .200 in. wide.

SUMMARY

Summarizing, this head has proven to be a good commercial product for these reasons:

1. High quality performance: This includes not only the extended frequency-response range from 30 to 18,000 cycles, but also high sensitivity, absence of microphonics, low bias-current requirements and low hum level due to its small size (approximately 3 cu/cm or .183 cu in./cm).
2. Low manufacturing cost in respect to quality: This is achieved by the manufacture of a larger number of identical parts, with a consequent reduction of cost per item, and by the reduction of the actual number of components in each head, particularly machined parts, such as mechanical clamps, terminal blocks, etc.
3. The reproduce head is identical with the record head, so that the user requires fewer spare parts for his recording machine.

Acknowledgment: The author is grateful to Mrs. E. Addington for valuable assistance rendered in the construction of the subject head.

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3. Wien Schott, "Einfluss der Schragstellung des Spaltes bei Intensitatschrift," *Zeitschrift der Techn. Physik*, vol. 17, p. 275, 1936.
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* 100% was defined as the recording level at which 2% second harmonic distortion is obtained at 400 cycles.

Physical Principles, Design and Performance of the Ventarc High-Intensity Projection Lamps

By EDGAR GRETENER

Dr. Edgar Gretener, A.G., Zurich, Switzerland

SUMMARY: The Ventarc lamps represent a new series of high-intensity carbon arc lamps for motion picture projection recently developed by the author at Zurich, Switzerland. The blown arc of the new lamp produces a distribution of brilliance which is highly advantageous for the illumination of the aperture. By using a new negative electrode the arc can be pushed up to an extremely high brilliance. The precision feed control of the Ventarc insures a perfect homogeneity and invariability of the screen illumination. The visible radiation of the arc is effectively concentrated on the projecture aperture by an entirely new optical system. Heating of the film is minimized by eliminating all invisible radiation. No surplus energy not useful at the screen has to pass through the film.

A new series of high-intensity projection arc lamps has been developed by the Edgar Gretener Company at Zurich, Switzerland. These lamps employ a number of fundamentally novel design features which are of considerable technical interest and which form the basis for this paper.

I. The Light Source

The light source employed in the Ventarc lamps is a "blown arc," invented by the author some years ago. Some historical remarks will be of interest before particulars of the present design are discussed.

Experiments were made in 1932 at the central laboratories of Siemens, Halske A.-G., Berlin, in connection with the development of a new super high-intensity lamp for use with lenticular color film projection systems. This lamp was to compensate, by increased crater brilliance, for at least part of the light lost in the color filters, and was to realize a distribution of brilliance over the positive crater rotationally symmetrical and constant in time. These requirements are essential for correct color rendition and brightness in projecting the Berthon-Siemens film. At that time a solution of this problem was found by employing air blast concentration of the arc, water-cooled jaws clasping the positive carbon immediately behind the

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crater and a radical reduction in thickness of the positive carbon shell.*

It is very interesting to see that the latest trends in development of normal high-intensity arcs for high light output follow fundamental principles already discovered in the course of the above-mentioned development activities, e.g., water-cooled contacts, positive carbons with thin shell and operation with short protrusion. In comparison with these, air-blast concentration of the arc has not, to date, been given the attention it deserves, in our opinion.

Investigation of brilliance distribution in the positive crater of a conventional 150-amp lamp with rotating positive carbon led to the following conclusions (Fig. 1):

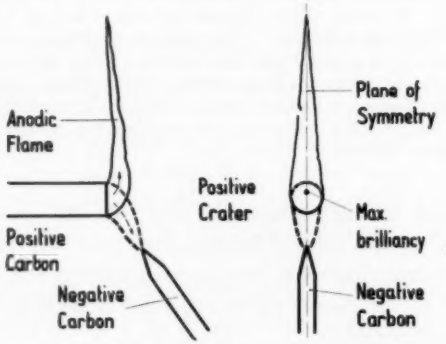

Fig. 1. High-intensity arc.

1. Taking the average in time, the brilliance distribution is symmetrical with respect to that plane, through the axis of the positive carbon, which separates the tail flame of the arc into two identical halves.

2. The peak value of brilliance is located above center, in that region where the arc tail flame issues from the crater, i.e., where the product of current density multiplied by the volume of gas assumes a maximum value.

The lack of rotational symmetry in the distribution of brilliance in a customary Beck arc is due to the fact that the current of anodic gases and the electrical current follow diverging paths outside the positive crater. Consequently, gas concentration and electric current density are not distributed symmetrically about the axis of the positive carbon.

* E. Gretener, "A brief survey of the physics and technology of the Berthon-Siemens color process," *Jour. SMPE*, vol. 28, pp. 447–463, May 1937.

Such observations led to the following conclusions, which were then made the basis for development of a new lamp (Fig. 2):

1. Both the current of anodic gases and the electric current have to be aligned with the axis of the positive carbon in order to obtain the desired rotational symmetry of brilliance distribution. This may be obtained with coaxial electrodes by directing a slightly converging conical air blast, along the positive carbon, which issues from the housing of the positive carbon and proceeds toward the negative electrode. This air blast produces an effective concentration of the anodic flame in the cylindrical space in front of the positive crater.

2. The current load may be raised to a maximum value by employing a positive carbon with a very thin shell. This shell is burned off by the oxidizing effect of the air blast, leaving only a thin crater edge,

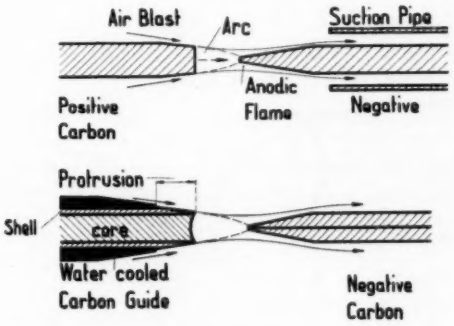

Fig. 2. Blown arc.

but the insulating effect of the air blast always confines the discharge column to the front of the positive carbon.

3. The positive carbon is surrounded by water-cooled jaws immediately behind the arcing end which protect the rear parts of the shell from oxidation by the air blast and avoid excessive calcination of the forward portion of the positive carbon. This measure prevents a decrease of the initial higher brilliance toward the lower more stable value which is generally observed after a new carbon is burned in.

4. The arc plasma is put into fast rotation by means of a current coil coaxial with the positive carbon. This increases the symmetry of distribution of brilliance with respect to the carbon axis, and also avoids formation of dark areas in the arc plasma, which would otherwise appear at extremely high current densities.

Rotation of the arc plasma is caused by the coil (Fig. 3) producing a magnetic field, H, which diverges from the positive toward the

negative terminal of the arc. Contrarily, the electrical flux lines, j, of the arc converge from the positive crater toward the tip of the negative electrode. Due to the rotational symmetry of both these fields, a resultant torque is produced which puts the arc plasma in rapid rotation about the arc axis.

As a result of all these features the blown arc possesses practically unlimited current capacity. Provided the thickness of carbon shell is suitably varied, the brilliance increases in linear relation with the arc current and seems to be limited only by the consumption rate of the positive carbon. The voltage characteristic of the arc is sufficiently positive so that this fact, together with the fixed shape of the

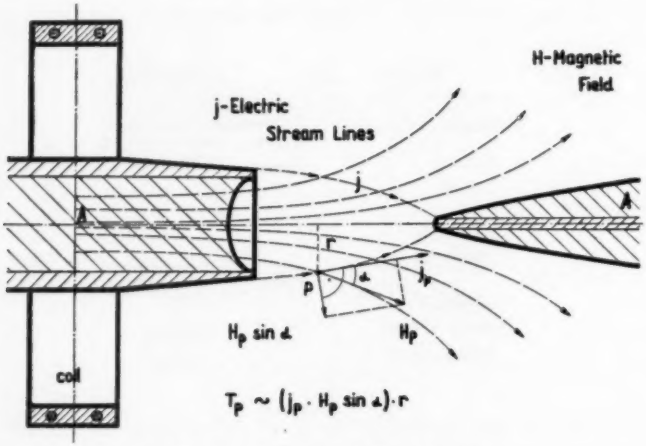

Fig. 3. Magnetic rotation of arc.

arc stream, permits the use of a power supply only slightly higher in voltage than the arc itself.

Practical difficulties are presented by formation of a mushroomlike growth of rare earth carbide on the tip of the negative electrode if the lamp is run with short arc gap and high consumption rate of the positive carbon, but such difficulties can be overcome by appropriate construction of the negative electrode.

Today the blown arc of the Ventarc lamp, which has undergone important further development during the past years, shows the following special features:

1. With increased current loading of the positive core, the maximum brilliance, as observed from outer mirror zones, is located between the center and the outer edge of the crater. A distribution of brilliance

across the positive crater is obtained as shown in Fig. 4, which permits uniform illumination of the film gate with high efficiency when used in conjunction with the optical system newly developed for the Ventarc lamps. Figure 4 shows the brightness variation across horizontal and vertical crater axes, in a plane perpendicular to the carbon axis, as recorded from a 50° angle of view to said axis. It is seen that the distribution of brilliance is very flat, thus giving a high average brightness in comparison with the peak value.

2. The air blast employed for arc concentration will not cause additional oxidation if appropriate choice is made of thickness and

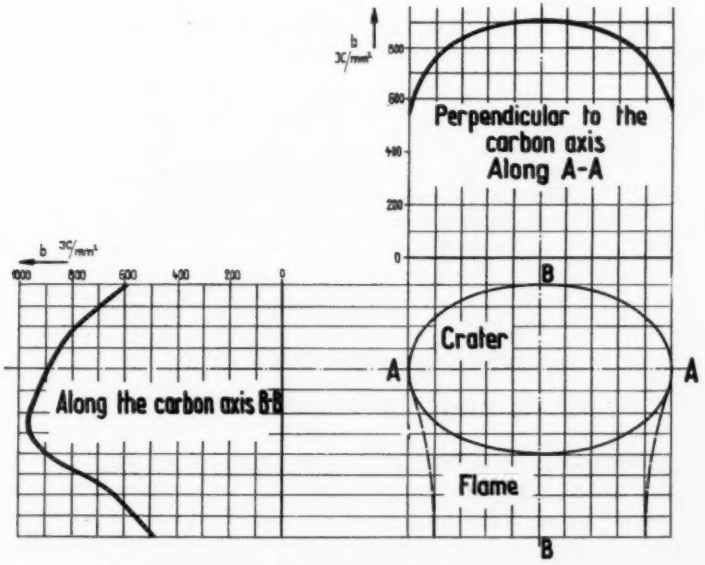

Fig. 4. Blown arc: distribution of brilliancy b; $\alpha = 50°$.

material of the carbon shell and of velocity of the air blast. Experiments employing nitrogen and carbon dioxide instead of air show practically the same result as regards brilliance and consumption rate.

3. Even without water cooling, the blown arc is stable and relatively indifferent to overload. If positive carbons of the best brand available today are used, no decrease of initial brilliance will be observed in the interval during which a new carbon burns in. It is, however, necessary that the carbon be pre-cratered in manufacture to the form it will assume in operation.

4. The Ventarc lamps do not produce soot, since complete oxida-

tion of the material evaporated from the core is effected by the continuous supply of fresh air.

5. Operation of the blown arc is independent of the position of the lamp in space, which is very convenient for projection with steep inclination of the optical axis.

6. Since the direction of air and vapor currents is symmetrical around the edge of the positive crater, this edge will always be formed perpendicular to the axis of the positive carbon. The necessity of rotating the carbon is thereby avoided, although this is quite indispensable in normal Beck high-intensity lamps operated with high current-density.

7. As viewed from the side, concentration of the arc by the air blast produces a very abrupt change in brilliance at the border line be-

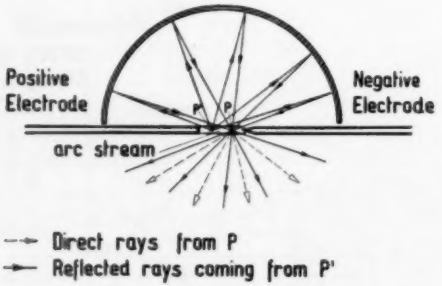

Fig. 5. Auxiliary mirror.

tween the positive shell and the intensely luminous anodic flame. As this border line is always at right angles to the carbon axis, it offers an ideal reference point for a high precision feed control which will position the positive crater exactly at the focal point of the concave reflector.

II. The Negative Electrode

Problems posed by the negative electrode of a blown arc have caused considerable difficulties. It must, however, be understood that in arcs of high current-density different conditions prevail for short gaps and long gaps.

1. For special purposes a lamp with an extremely long gap was developed, which produces a luminous flux of 5,000,000 lm drawing 350 amp at 180 arc volts with a gap of 80 mm.

By the use of a small water-cooled auxiliary mirror, an inverted image of the arc was focused on the arc itself (Fig. 5). Thereby the

brilliance measured at right angles to the arc axis was raised to a value of at least 1100 to 1200 IC/mm² (International Candles per square millimeter) along the entire length of the arc (Fig. 6). The positive carbon employed was 12 mm in diameter with a core of 9 mm; the negative carbon was 11 mm in diameter. In spite of the enormously high output of the arc and increased consumption rate of the positive carbon, the negative electrode gave no difficulty, since sufficient oxygen penetrated the arc to prevent formation of mushrooms on the negative tip. Therefore, by operating a blown arc at the relatively high voltage necessary with a normal high-intensity arc with angular trim, the gap can be enlarged so that formation of carbide deposits on the tip of the negative carbon is avoided.

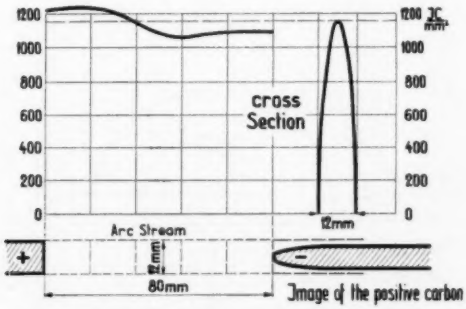

Fig. 6. Brilliancy of arc-stream at 350 amps, 180 volts.

2. For projection lamps, arc voltage should be as low as possible because a long arc wastes energy with additional heating of the lamp house.

Attempts were made to reduce the formation of carbides at short arc lengths by appropriate choice of material for the core of the negative electrode. A basic solution to these difficulties could not be obtained in this way, however.

Formation of mushroomlike deposits is caused by evaporation products which deposit on the negative tip inside the plasma of the arc, where they cannot be oxidized. Thus the deposit on the negative tip continually enlarges. This difficulty is avoided if the evaporation products tending to deposit on the negative tip are transported instead out into the air, where they rapidly oxidize.

This continuous transport is accomplished by replacing the customary rod-shaped negative electrode with a slowly rotating thin disc of graphite, the negative spot of the arc being located on the sharp

edge of this disc (Fig. 7). The gases of the arc flame are exhausted by two suction pipes, one on each side of the disc. Reduced thickness of the graphite disc, sharpening of its edge, and arranging of the disc in a meridianal plane of the optical system reduce additional shadowing of the luminous flux by the cathode disc to a negligible value.

This disc-shaped cathode permits satisfactory operation of a highly loaded blown arc with extremely short gap. Measurements taken in 1948 (Fig. 8) show continuous increase of the brilliance for increasing arc currents. The brilliance attainable in such lamps seems to be limited only by the consumption rate of the positive carbon. A 12-mm positive carbon with 9-mm core, operated at 420 amp, 75 volts produced 2000 c/mm^2 at 60° to the carbon axis, with a consumption rate of 62 mm/min. This consumption could be reduced by using direct water-cooled jaws in combination with special carbons developed

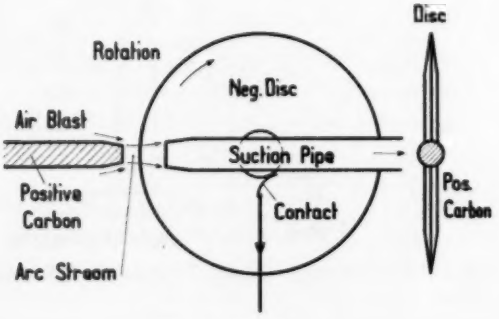

Fig. 7. Disc lamp.

by National Carbon. It must also be understood that this brightness value in no way represents a limit that may not be surpassed.

In such a lamp an approximately linear relationship exists between arc current and brilliance. The positive carbon used in the present lamp is correctly adapted to a current of 200 amp. For higher values of arc current, shell thickness would have to be reduced. By appropriate choice of material, carbon shell thickness and velocity of the air blast, even better results might be obtained.

In these experiments, the core of the positive carbon employed was designed for normal searchlight use and therefore was of special composition to ensure stability of the arc. Since this problem does not arise in the blown arc, the salts in the carbon may be chosen on the basis of maximum brilliance only thus yielding even more favorable results.

A practical difficulty in adapting the disc arc lamp for use in cinema projectors is presented by the comparatively short focal length of the reflector. In order to ensure a sufficiently long period of operation, the diameter of the disc must exceed the focal length of the usual mirror. In order to locate the crater of a disc lamp at the focal point, a slot would have to be provided in the reflector to accommodate the rear part of the disc. This would complicate lamp design, particularly for the suction pipes, which would then interfere with the support, the drive and the means for current supply to the cathode discs.

Such difficulties are avoided by employment of a ring cathode in place of a disc (Fig. 9). The ring passes around the positive head and the arcing spot is located on the sharpened inner edge of the ring.

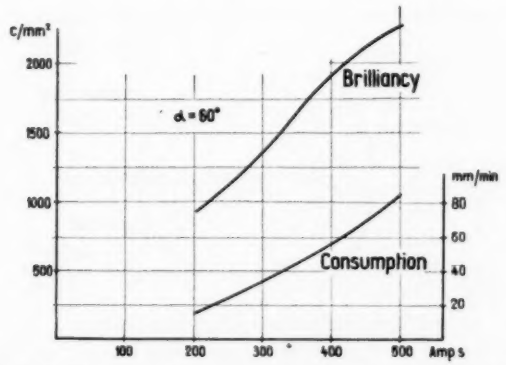

Fig. 8. Brilliancy and consumption rate of a short blown arc.

Appropriate design and arrangement of the lamp mechanism reduce the additional shadowing caused by the cathode ring to a negligible value.

The active part of the cathode ring is made of artificial graphite set in a metal mounting. The life of a single ring in a 100-amp Ventarc lamp is approximately 15 hr. Easy replacement is provided. The drive mechanism for rotating the ring as well as the supply of current to the ring is effected through the metal mounting.

The inner edge of the ring is guided by two ceramic rollers located on each side of the positive head, so that the length of the arc gap is practically independent of consumption of the inner edge. The ring support may, however, be adjusted manually to regulate the value of arc current, although no such adjustment is required during a normal projection period.

Extremely high operational stability is obtained by a Ventarc lamp with the ring cathode, as the arcing spot on the ring is kept practically fixed in space.

Striking of the arc is effected by feeding the positive carbon forward until it touches the cathode ring and subsequently withdrawing it to the normal operating position.

III. CARBON FEED CONTROL

1. Separate positive and negative carbon feed controls are employed in the Ventarc lamps. Requirements for positive feed control, to maintain the crater in the focal plane of the illumination system, increase in precision with the efficiency of the illumination system.

For accurate photoelectric feed control, the shape of the arcing edge of the positive crater must remain constant and in a plane at

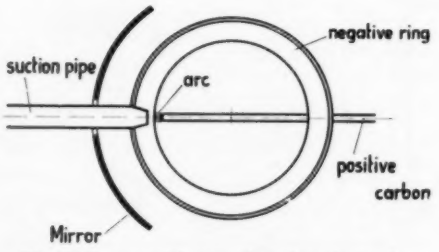

Fig. 9. Lamp with negative ring-electrode.

right angles to the axis of the carbon, a condition readily met by the air-blown arc.

In order to obtain maximum sensitivity of the regulating system, it is desirable to increase, as far as possible, the sharp change in brilliance between the forward edge of the positive shell and the base of the anodic flame.

A blown arc is capable of meeting these requirements as extremely high brilliance is obtained in front of the positive carbon by the concentration of the anode flame. This difference in intensity between the anode flame and the positive carbon is greatest in the blue and ultraviolet spectral region.

With these favorable features a blown arc permits the use of a very simple and accurate positive feed control (Fig. 10). This method may be employed without difficulty, even in blown-arc lamps with arc currents as low as 25 amp. By means of a small lens the crater edge is imaged at right angles to the carbon axis upon a slotted diaphragm.

Behind the slot is a phototube (RCA 929) which is particularly sensitive to blue and ultraviolet radiation. This phototube governs the feed of the positive carbon by a glow discharge tube and magnetic clutch. The feed mechanism is actuated as soon as the carbon burns back beyond its normal position, and when the crater protrudes a bit too far, the feed control is stopped. Such a control is accurate within ± 0.1 mm and is practically free of inertia so that it may execute several feeding cycles per second. As the regulation system does not contain electrical contacts, the operational reliability is very high, with practically no breakdowns. Any manual misplacement of the positive carbon is automatically corrected.

2. In the smaller Ventarc lamps equipped with a conventional negative carbon, the negative feed control is based on keeping the arc

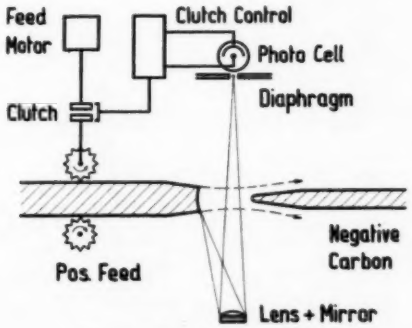

Fig. 10. Positive regulation.

current constant. If current is low, the negative carbon is fed forward, shortening the arc gap until the current increases to its standard value. If the current is high, the reverse effect is obtained by increasing the length of the arc.

This method of feed control reaches accuracies of $\pm 2\%$ by an extremely simple design without electrical contacts and is consequently of very high reliability.

In large Ventarc lamps equipped with disc or ring cathodes, the cathode is manually adjusted so that the gap corresponding to the desired standard value of the arc current is obtained. Due to the extremely low consumption rate of the cathode, resetting of the cathode is not necessary during a projection period.

3. Because of the high stability and constant brilliance in a blown arc and because of the favorable conditions for positive and negative electrode feed control, a steadiness of screen illumination is obtained

amounting to ±2% to 3% over a whole projection period. Moreover, this is accomplished automatically and independently of the attention of the operator.

Life tests of the positive feed control, extending over more than 10,000 hr, show excellent results. Two Ventarc lamps in commercial use in a motion picture house at Zürich throughout the past year have required no readjustment of the positive feed control up to the present time.

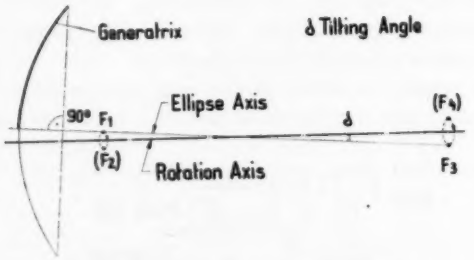

Fig. 11. Generation of new mirror.

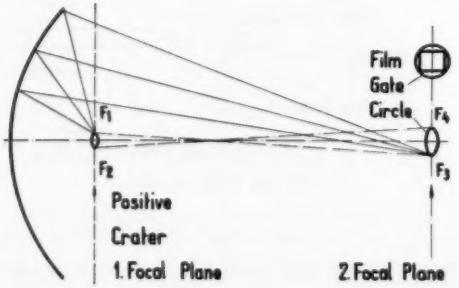

Fig. 12. New mirror for Ventarc lamps, four-focii type.

IV. The New Optical System of the Ventarc Lamp

1. The Ventarc lamps are equipped with a new optical system which is adapted to the particular distribution of brilliance of the blown arc and therefore gives excellent uniformity of screen brightness with high light efficiency. Referring to Fig. 11 the reflecting surface of the mirror is generated by rotating round an axis the arc of an ellipse the main geometrical axis of which is inclined to the rotation axis by an angle, δ. The value of this tilting angle, δ, is determined by the desired location of the crater images on the aperture plate and the focal distances involved (Fig. 12). As the axis of the generating

ellipse is tilted in such a way that its two focal points do not lie on the optical axis, the reflector possesses two focal circles, oriented at right angles to the optical axis of the projection system. One of these circles is made to coincide with the crater edge and the second one is made to circumscribe the aperture (Fig. 12).

Ideal properties of such an optical illumination system are obtained

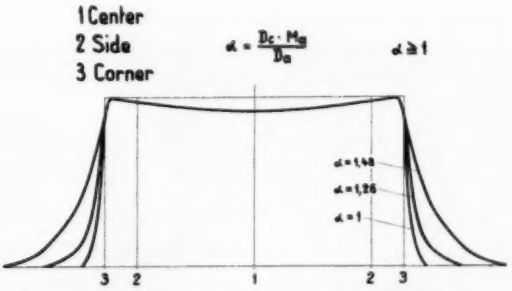

Fig. 13. Light distribution through the film aperture.

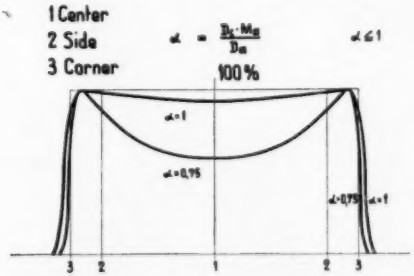

Fig. 14. Light distribution through the film aperture.

if the crater diameter, D_c and the axial magnification ratio of the mirror, M_a, are made to satisfy the following condition:

$$D_c \cdot M_a = D_g \cdot \alpha$$

in which D_g is the diameter of the focal circle at the aperture, and the constant α has a value of unity.

In this case the light distribution on the aperture is as shown by curve I, Fig. 13.

With the same focal circle, D_g, maintained at the aperture, but with $D_c \cdot M_a$ made greater than D_g, i.e., $\alpha > 1.0$, diverging distribution curves are obtained as additionally shown in Fig. 13. The greater extent of these latter curves is the result of crater images tangent inside the

focal circle, but larger than the aperture diagonal and so indicative of reduced efficiency.

If the product, $D_c \cdot M_a$, is smaller than, D_g, i.e., $\alpha < 1.0$, light distribution curves are obtained (Fig. 14) which indicate that the projection screen is now darkest in the center. Here the crater images tangent inside the focal circle are too small to carry sufficient light to the center of the aperture.

This particular type of reflector facilitates adaption of the optical system to any particular projector; for in contrast to the customarily employed elliptical reflectors, the angle of inclination represents an additional degree of freedom in design.

2. In optical illumination systems for projection lamps one condition is of paramount importance: the axes of all light beams passing

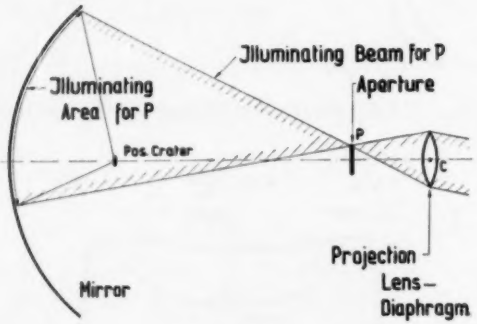

Figure 15.

through every point, P, in the aperture must intersect at the center of the entrance pupil, c, of the projection lens (Fig. 15).

In order to obtain a high efficiency of illumination, only such parts of the reflecting surface should appear luminous from a point, P, as are cut out of the reflecting surface by the extension of a cone having its apex at P, and with the pupil of the projection lens as its base.

The new illumination system for the Ventarc lamps has been laid out to meet fully this requirement, in combination with a projection lens of 100-mm (4-in.) focal length.

A very simple and conclusive test for this quality of the reflector may be made in the following way: the positive crater is replaced by a screen of homogeneous luminosity and photographs of the reflector are taken from points at the center and corners of the aperture, showing the portions of the mirror surface that appear luminous from these points. The theoretical form of the luminous areas on the mirror

to be expected for each of these points may be calculated and compared with the actual form of the areas shown by the test photographs. This method provides a convincing criterion for the quality of the reflectors. For instance, a measure of light distribution over the illuminated spot on the aperture plate is obtained directly from the ratio of the size of the luminous areas in the center to the size of such areas at the sides or corners. Figure 16 represents such a test

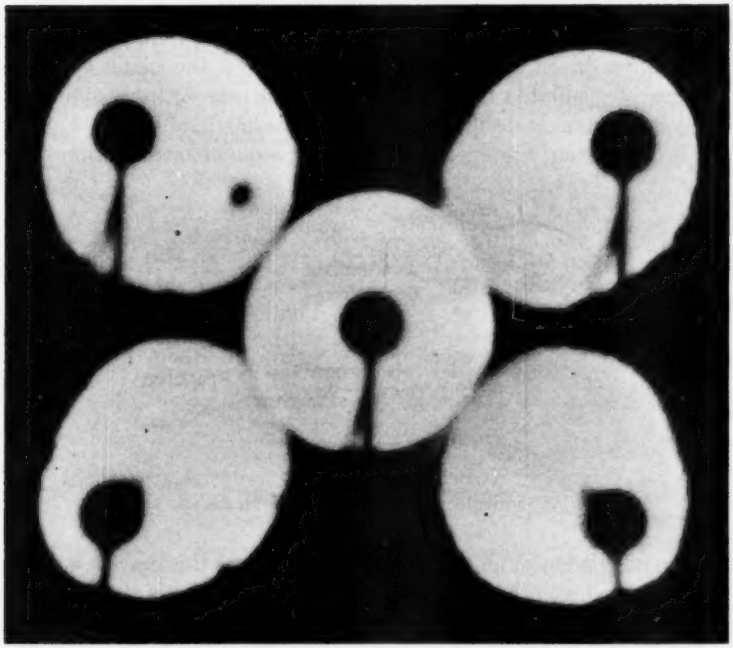

Fig. 16. Test photograph.

photograph showing the illuminated areas of a Ventarc reflector as seen from the center and corners of the film aperture.

3. The requirement, $D_c \cdot M_a = D_g$, can be met with reasonable expense in the conventional coaxial optical system only for small diameters of the crater corresponding to arc currents up to 75 amp. In view of the minimum length of carbon which must be accommodated between the crater and the film aperture at higher currents, mirrors of very large diameter and excessive cost are demanded.

To avoid such difficulties a deflected light path is employed in the

Ventarc lamp with highest light output. Figure 17 shows the actual arrangement: the positive carbon is arranged vertically (in the lamp house), the concentrating air blast is directed upward so that the normal thermal rise of the flame gases adds to the effect of the blast. The optical axis of the illumination system is deflected by a mirror into alignment with the projection axis. The positive carbon passes through a slot in the deflection mirror, and its necessary length no longer affects the dimensions of the illumination system.

As it is impossible to satisfy all desirable conditions—such as homogeneity of illumination on the aperture plate, optimum speed of the illumination beam and appropriate location of the plane of a diaphragm—by suitable formation of the reflecting surfaces alone, the foregoing system is designed to give an intermediate image (Fig. 17) much larger than the aperture. The subsequent introduction of an

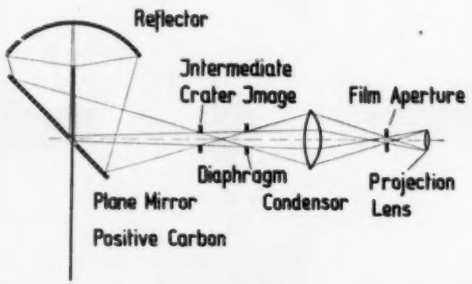

Fig. 17. Optical system for Ventarc with ring-cathode.

additional condenser lens is not objectionable, as this may be surface-treated to reduce reflection losses. The same is true of the deflection mirror which may be so constructed with a reflection index of 97%.

4. The illumination system of a Ventarc lamp, designed for a crater diameter of 6.3 mm, produces a cone of light at the aperture of $f/1.8$ speed. A similar system designed for a larger crater would only increase the speed of the light beam at the aperture, and this would be useless with present-day projection lenses, already filled by an $f/1.8$ cone. A higher light output may be attained only by increasing the brilliance of the positive crater, i.e., by increasing the current density and consequently the consumption of the positive carbon. The layout of the Ventarc lamp with ring cathode provides for this possibility, as the essential dimensions of the interior parts and of the lamp house offer sufficient space to permit an increase of the positive carbon loading to 150 or 200 amp.

V. SCREEN LUMENS

1. A most important requirement for a good projected picture is effective luminous flux arriving at the projection screen. Assuming uniform illumination of the aperture, the following formula is valid for the luminous flux, L, illuminating the film:

$$L = l \cdot F \cdot \Theta$$

where l represents the brilliancy of radiation in the plane of the aperture measured in candles per mm^2; F, the area of the aperture in mm^2; and Θ, the solid angle by which the pupil of the projection lens is seen from the film. An evaluation of this very simple relation is represented by Fig. 18, in which shadowing caused by the positive carbon guide mechanism is neglected.

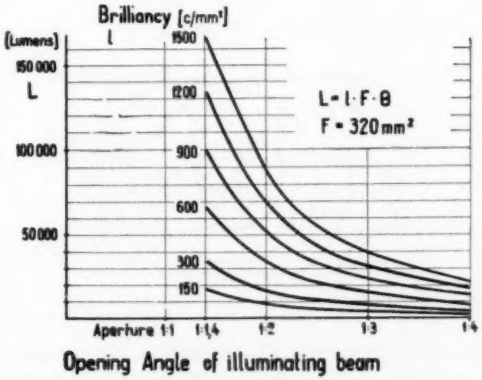

Fig. 18. Lumens through the film aperture.

It is not, however, the peak value of brilliance measured at the most advantageous angle and at the brightest spot of the positive crater which is significant here, but rather the average of the brilliance over the crater surface at all angles. This average brilliance, which determines the luminous flux through the aperture, is a considerably smaller fraction of the peak brilliance than is generally presumed. For instance, the assumption of a homogeneous illumination of the image field with an average brilliancy of only 750 c/mm^2, leads to the amazing value of 46,000 lm in the aperture plane.

The figures of peak value of brilliance in the positive crater generally contained in technical publications ought to be supplemented by a specification of the average brilliance all over the utilized surface

of the crater, in order to avoid false impressions of the performance of different light sources.

2. The heat capacity of the film is limited, and may not exceed a maximum value of 0.5 W/mm² even if forced air cooling of the film is employed. It is therefore necessary to restrict the luminous flux to the useful luminous region of the spectrum, so that maximum lumens through the aperture are obtained without exceeding the admissible radiation density.

3. Next to uniform distribution and constancy in time, uniformity in color of the screen illumination is of great importance. Any variation of color across the screen is decisively detrimental to the artistic value of projection.

A very good criterion for the uniformity in color of the screen illumination is obtained by measuring the relative value of the green and the red component at the center and the corners of the screen by means of a phototube and color filters.

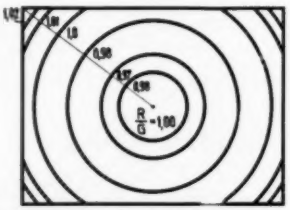

Fig. 19. Red-to-green ratio of the screen illumination for the Ventarc, 50 amp.

The results obtained with the Ventarc 50-amp are indicated in Fig. 19. It must be emphasized that with Ventarc lamps the distribution of such values is rotationally symmetrical, whereas with customary high-intensity lamps symmetry only exists relative to a vertical line through the center of the picture. Extension of such measurements beyond the corners of the screen is recommended, as this permits prediction of the extent to which the red-and-green component in the corners will deviate if slight maladjustment of the projection system occurs.

In view of the considerable importance of color uniformity, standard tolerances should be set up for the red-to-green ratio on the projection screen.

VI. Light Output of the Ventarc Lamps

The light output of the Ventarc lamps is illustrated by Fig. 20. The types of the series hitherto developed cover an effective screen

illumination range from 3550 up to 30,000 lm with arc currents of 20 to 100 amp. All such lamps are equipped with reflector illumination systems.

The ratio of screen lumens to power consumption may be employed as a quality coefficient of a projection lamp (Fig. 20). An average coefficient of 6 lm/w is obtained by the Ventarc lamps where the

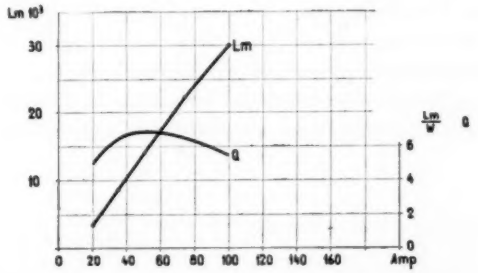

Fig. 20. Screen lumens of the Ventarc lamps side-to-center ratio 80%.

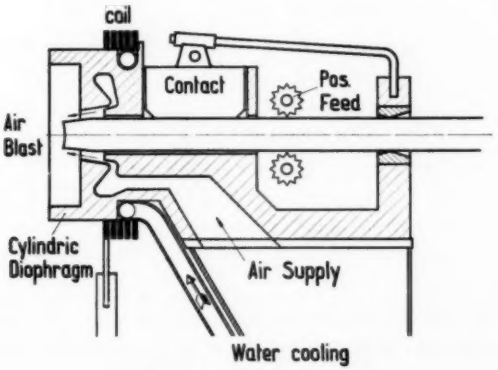

Fig. 21. Positive head.

brightness at the lateral boundaries of the screen amounts to at least 80% of the value at the center.

VII. Construction Features of the Ventarc Lamps With Ring Cathode

1. The positive head (Fig. 21) is water-cooled and the carbon support and contacts for current supply are in good thermal contact with the water-cooled parts. As no decrease of the brilliance is observed after a new carbon has properly burned in, direct water cooling of the

current contact is dispensed with as that would require considerable complication of design. As far as a reduced consumption rate can be achieved by using the special carbons of National Carbon, direct water-cooling of the jaws can be provided.

The magnet coil is mounted behind the water-cooled parts of the positive head. It is thus protected against direct radiation and its current loading may consequently be made exceedingly high.

The blower nozzle is made of a special acid- and heat-resistant steel. The nozzle may easily be replaced, but under conscientious operation the attainable period of life is very long.

The air velocity may be regulated by means of a valve so that the optimal value for any current load of the positive carbon may be set exactly.

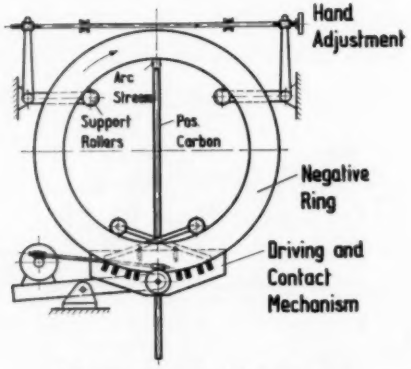

Fig. 22. Negative ring system.

To avoid excessive irradiation and heating of the lamp house by the highly intense anode flame, the water-cooled positive head is equipped with a cylindrical diaphragm, provided with the necessary ports for the observation of the crater and of the positive feed control. Heating of the lamphouse is effectively reduced by this diaphragm.

2. The ring cathode poses some constructional problems (Fig. 22), as, for instance, the mounting, drive and current supply of the cathode ring.

The two rollers previously mentioned, which guide the ring at substantially constant arc length, are shown in the vicinity of the positive head.

A symmetrical application of the current to the arc through both halves of the ring is essential as distortion of the arc would result from

the magnetic fields excited by an unsymmetrical admission of current. Facilities permitting an easy replacement of the cathode ring are of practical importance; the rear wall of the lamphouse may be opened as a whole for the mounting of a new ring.

3. The cathode ring and deflection mirror are arranged so that the ring completely embraces the mirror. Shadowing of the illuminating beam is thereby minimized. The somewhat higher shadowing occurring at the screen center improves the uniformity of screen illumination.

4. Compressed air is provided by a blower separated from the lamphouse. The particular construction of the lamp (Fig. 23) permits utilization of one single blower to supply air alternately to two lamps.

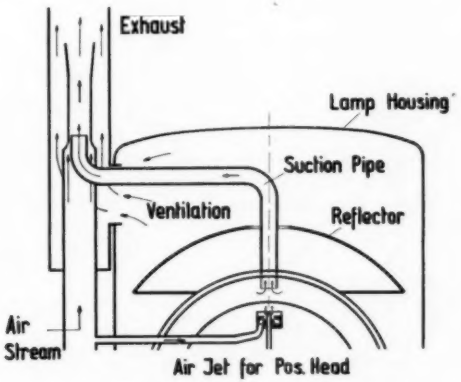

Fig. 23. Air jet system.

This solution presents important technical and economical advantages, namely:

(a) The hot flame gases do not pass through the blower so that difficult technical problems, e.g., excessive heat, choking by deposits, etc., do not arise.

(b) The blower runs on cold air thus obtaining a higher efficiency.

(c) The blower is mounted separately from the lamp, so that constructional complications such as spring mounting, silencing, heat insulating and access for cleaning purposes are avoided.

(d) Since only one blower system is required for two lamps, this may be built of higher quality. Silencer and dust filter are required only once, but simultaneously serve for two lamps. The diameter of the blower wheel may be increased and the rotation speed lowered as no restriction of the space exists. Consequently the commutator

motor hitherto required for Ventarc lamps may be replaced by a squirrel-cage motor which is superior on account of its sturdiness and service-free operation.

Because of the fixed position in space of the ring cathode, the Ventarc lamp provides additional safety against damaging of the positive head, in case of failure of the positive feed control. In such a case, the positive carbon would burn back until the arc was extinguished by the minimum current relay or by the air blast.

APPENDIX

The particular form of the discharge of the blown arc permits determination of the absorption rate of the arc plasma A, the volumetric brilliance, b_v, and the saturation value of brilliance, b_{max}, for increasing

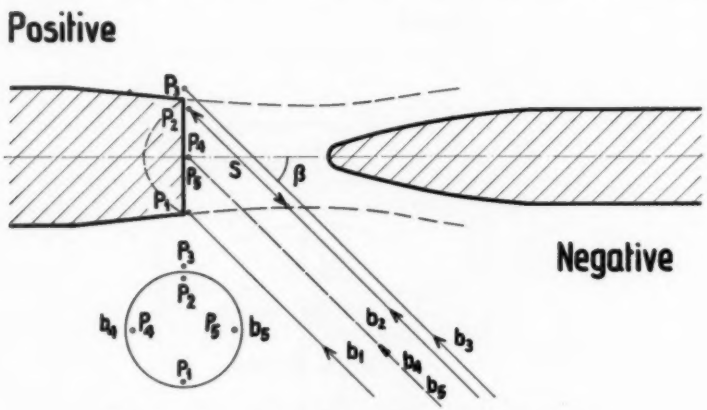

Fig. 24. Blown arc: volume brilliancy and absorption.

diameters of the carbon assuming constant current density in the positive crater. This saturation value in the interesting range rises proportionally with the arc current. By measuring the values of brilliancy, b_1, b_2 and b_3 at the respective points, P_1, P_2 and P_3 in a direction inclined by an angle, β, to the axis of the carbon, a very simple calculation arrives at the following relations (Fig. 24):

$$A = \frac{1}{S} \cdot \log_e \frac{b_1}{b_2 - b_3}$$

$$b_v = A \cdot \frac{b_1 \cdot b_3}{b_1 - (b_2 - b_3)}$$

or

$$b_{max} = \frac{b_v}{A} = \frac{b_1 \cdot b_3}{b_1 - (b_2 - b_3)}$$

S stands for the length of the line of sight through the arc stream looking towards points P_2 or P_3.

These relations hold for a very shallow crater as indicated by Fig. 24. In case of a deeper crater the value b_1 has to be replaced by $b_1^* = \frac{1}{2}(b_4 + b_5)$ which is self explanatory with regard to Fig. 24.

By inserting the particular values measured with a 200-amp blown arc

$$b_1 = 700 \quad b_2 = 1000 \quad b_3 = 950 \quad [\text{IC/mm}^2]$$

the following figures are obtained:

$$\begin{aligned} A &= 0.25 \\ b_v &= 256 \ [\text{IC/mm}^3] \\ b_{max} &= 1025 \ [\text{IC/mm}^2] \end{aligned}$$

In this case the absorption of a layer of the arc plasma 1 mm in thickness amounts to 22%. The absorption rate of the arc plasma rapidly increases towards the region of short wavelength. This observation provides an explanation for the occurrence of brown areas inside the plasma at high current-density.

NOTE: A 100-amp model of the new lamp was set up and demonstrated at the SMPTE Chicago Convention.

The High-Speed Photography Of Underwater Explosions

By PAUL M. FYE

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SUMMARY: A brief review of the techniques used in photographing underwater explosions at the Underwater Explosives Research Laboratory and the Naval Ordnance Laboratory for the past several years will be given. The Fastax (35-Mm), Eastman Hi-Speed and a rotating-mirror frame camera have obtained pictures ranging in speed from 2000 to 30,000 frames/sec. Explosions of charges weighing up to one pound have been photographed at depths down to two miles. In the very deep water photography the equipment which synchronized the explosion with the flashbulbs, timers, etc., was self-started by means of a pressure switch. Typical results will be shown.

MANY TYPES of transient phenomena have been studied by means of high-speed photography. In the past few years, underwater explosion phenomena have been included in such studies at a number of laboratories, notably the David Taylor Model Basin in this country and the Naval Construction Research Establishment in Great Britain.[1] Presented here is a brief outline of the work by a number of people at the Underwater Explosives Research Laboratory (UERL) and the Naval Ordnance Laboratory (NOL) where methods have been developed for the photography of explosive charges ranging in size from 1 oz to 300 lb. The techniques used by other laboratories, in most cases, have restricted the explosion to that which can be contained in a tank and consequently the charge size has usually been about 1 gram.

The work described here has all been conducted in the ocean from a ship. In general, two types of high-speed photography have been used in the UERL studies of underwater explosion phenomena: (1) the photography of shock waves[2] by means of a short-duration light source (10^{-6} sec); and (2) the photography of explosion bubble expansion and contraction by means of motion pictures.[3]

As is well known, an underwater explosion results in a rapidly expanding shock wave followed by a succession of pressure pulses.[4] The later pressure pulses are caused by the repeated collapse of the gas globe formed by the hot expanded gaseous products of detonation.

Presented: April 26, 1950, at the SMPTE Convention in Chicago. This paper is based in part on work done for the Bureau of Ordnance under Contract NOrd 9500 with the Woods Hole Oceanographic Institution, Woods Hole, Mass., and in part on work at the Naval Ordnance Laboratory.

It is the photographing of the oscillations of this gas bubble with which the following is concerned.

Some of the requirements of such photography are: (1) sufficiently clear water to permit the proper spacing of equipment and explosive charges; (2) appropriate cameras contained in water and explosion resistant cases; (3) synchronization of the lights and camera with the detonation; (4) light sources; (5) precise speed control of the camera or timing marks on the film; and (6) a rig for mounting and maintaining the position of each component.

The requirement of very clear water results from the camera-to-object distance required in some of this work. For example, using a 2½-in. focal length lens on the Eastman Hi-Speed camera, the angle of view under water is only about 5 deg and the target must be 40 ft away to get a 4-ft field. Sufficiently clear water was found off the Florida coast near the Bahamas and in the Caribbean Sea. In general, clear water can be found in the tropical latitudes where it is not contaminated by shore drainage. A convenient measure of the water clarity is obtained by means of a Secchi disk which is simply an 8-in. white circular disk. The limiting depth to which it can be lowered in the sea and remain visible is a reliable and reproducible measure of clarity.[5,6] The waters mentioned had a Secchi disk reading ranging from 135 ft to 160 ft. A rough rule for such photography is that adequate resolution can be obtained for a camera-to-target distance equal to about one-half the Secchi disk reading.

The cameras used in this work included the Eastman Hi-Speed, the 35-Mm Fastax and a rotating-mirror frame camera of NOL design. These cameras were shock-mounted in a heavy, watertight case to prevent damage from an explosion. Figure 1 shows the case used with the Eastman camera. The NOL designed camera, which was used at depths as great as 2 miles in the ocean, was enclosed in a spherical case which was 22 in. ID and had a 1¼-in. wall. The camera lens viewed these deep explosions through a 1-in. thick window covering a 1¼-in. hole.

The camera designed by S. J. Jacobs (NOL) and A. A. Klebba (Woods Hole Oceanographic Institution) is essentially a modified Bowen camera. The image is focused on a spinning mirror which has the focal axis of the taking lens system for its axis of rotation. The plane of reflection of the mirror is 45 deg to this axis. The image is thus reflected through the framing lens to the stationary film. One hundred framing lenses provide 100 pictures. With the mirror revolving at the rate of 18,000 rpm, 100 pictures can be taken at the rate of 30,000 fps. An auxiliary shutter prevented multiple exposure.

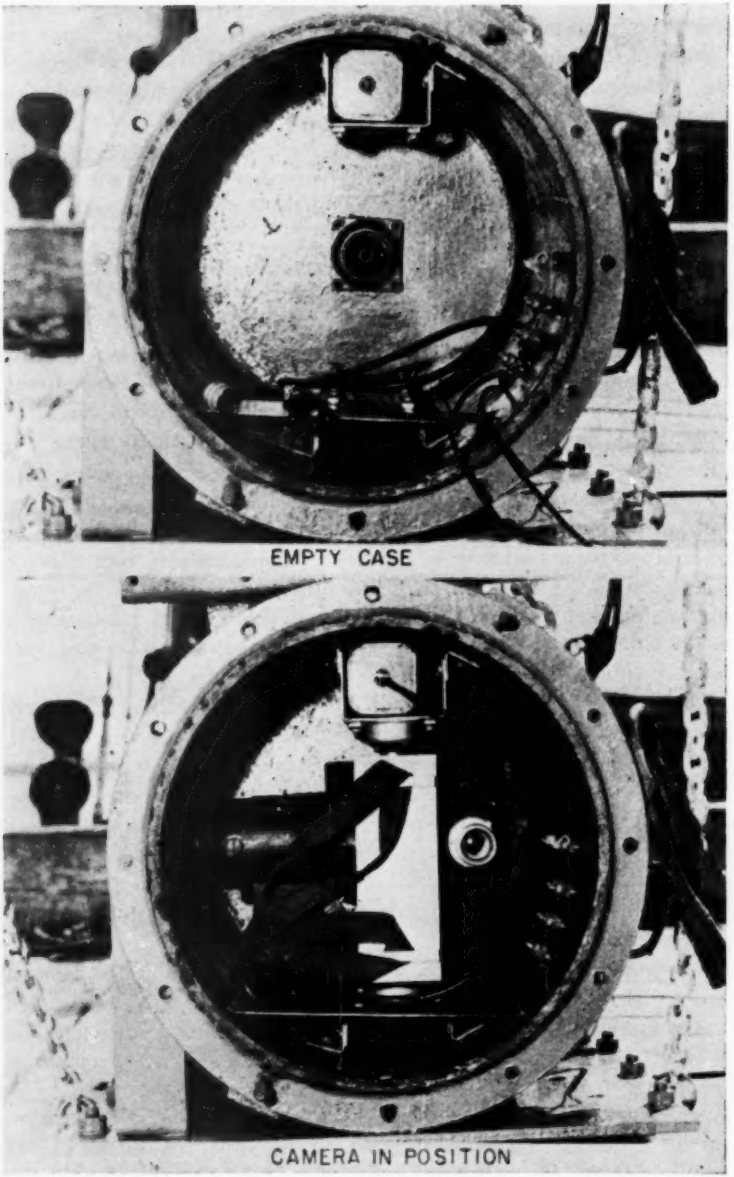

Fig. 1. High-speed camera and "explosion proof" case.

Such frame speeds were required for the very deep photography in which the oscillations of the explosion bubble are much more rapid than in shallow water. The Eastman and Fastax cameras were not used at depths greater than 1,000 ft.

The light source most commonly used consisted of a number of focal plane flashbulbs, having a duration of about 70 msec (milliseconds). On occasions when a longer light was necessary, such flashbulbs were fired in series. Miniature bulbs were used for the very deep work. It was necessary to provide protection from the explosion for these bulbs by a watertight case having a Lucite window.

For the work at less than 1,000 ft. with the Eastman and Fastax cameras electrical power to operate the cameras and a timing signal was provided through cables from the ship. Since knowledge of the precise depth at which the experiment was performed was very important, a depth gage was used to measure the static pressure and hence the depth to within 2%. For some experiments a Bourdon gage was photographed by a small camera at the instant of the explosion. For others the Bourdon gage element actuated a potentiometer which was one arm of a Wheatstone bridge. The latter method permitted continuous reading by means of cables to the surface and consequently was more convenient for an accurate presetting of the depth.

It was impossible to have electrical cables leading from the camera to the surface for work at depths of one and two miles. The power for the camera in this case was supplied by miniature wet cells, and the entire equipment was self-operated after the closing of a depth switch. The sequence of events necessary to obtain photographs included: the starting and stopping of the camera motor, the operation of the shutter, the firing of the 1-lb explosive charges, and the firing of 20 to 40 No. 6 focal plane flashbulbs. These events, which had to be synchronized with a precision of the order of ¼ msec, were started by the closing of a switch triggered by hydrostatic pressure. Two pressure switches, one actuated by a Bourdon gage mounted in the camera case and one which involved the movement of a spring-backed piston, had an accuracy of better than $\pm \frac{1}{2}\%$ in depth.

Since the Fastax camera did not have a built-in firing switch, it was necessary to fire the charge from the laboratory ship. In order to fire the charge automatically when the camera had reached maximum speed and the photoflash bulbs were near peak intensity, and to turn off the camera, the firing circuit and camera power circuit were combined as shown in Fig. 2.

A typical operation would be as follows: when the safety switch is

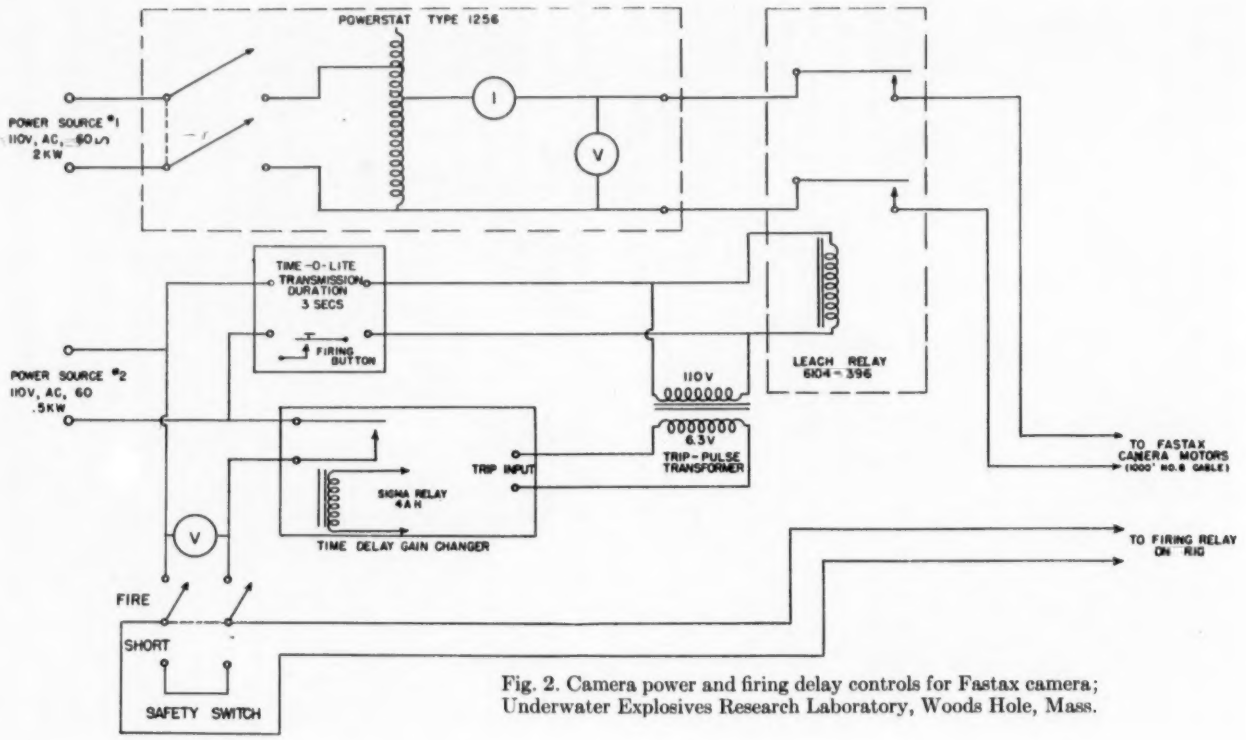

Fig. 2. Camera power and firing delay controls for Fastax camera; Underwater Explosives Research Laboratory, Woods Hole, Mass.

thrown and the firing button on the Time-O-Lite* is pressed, a 110-v current is transmitted to the camera power relay and trips the electronic time delay.[3] The camera then starts and is up to speed in a little more than a second. At 1.5 sec, the time delay gain changer closes an internal relay which transmits the 110-v a-c power to the firing relay on the rig. This fires the flashbulbs and the charge, the latter being delayed a few milliseconds by a series resistor so that the bulbs can be at maximum brilliance when detonation occurs. After 3 sec, the Time-O-Lite turns off the power to the camera relay, thus stopping the camera after the film has run through. These times may easily be changed to suit other conditions.

As shown in Fig. 3, all the necessary components in their respective pressure cases were mounted on a rigid frame. Such steel frames,

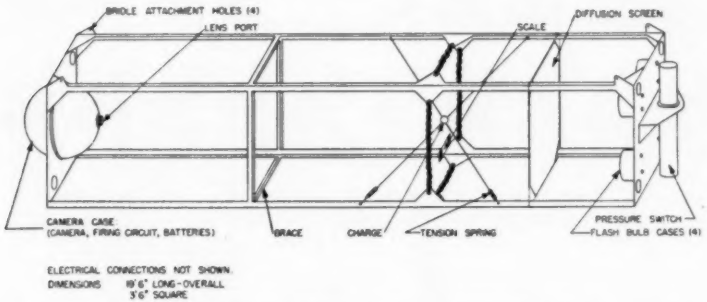

Fig. 3. Deep sea camera apparatus. Electrical connections not shown. Dimensions: 19 ft 6 in. long, over-all; 3 ft 6 in. square.

built of channel and angle iron in lengths varying from 10 ft to 40 ft, were used for explosive charges weighing up to about one pound. Since the operation of the camera was automatic with the closing of the depth switch, this entire rig, weighing about 1,200 lb, was simply lowered to the preset firing depth by a single steel cable.

In Fig. 4 are shown some typical results using the Eastman Hi-Speed camera. Here is shown the explosion of 25 grams of tetryl at a depth of 350 ft. The scale above the charge is 12 in. long. The charge was placed 20 ft from the camera where the field of view was about 20 in. × 28 in. The first frame shows the undetonated cylindrical charge. Detonation occurred between the first and second frames. The bubble, in this case, grows to its maximum size in 5.5 msec and has collapsed to a minimum at the end of 11 msec. The

* Time-O-Lite Master Model M-49, Industrial Timer Corp., Newark, N.J.

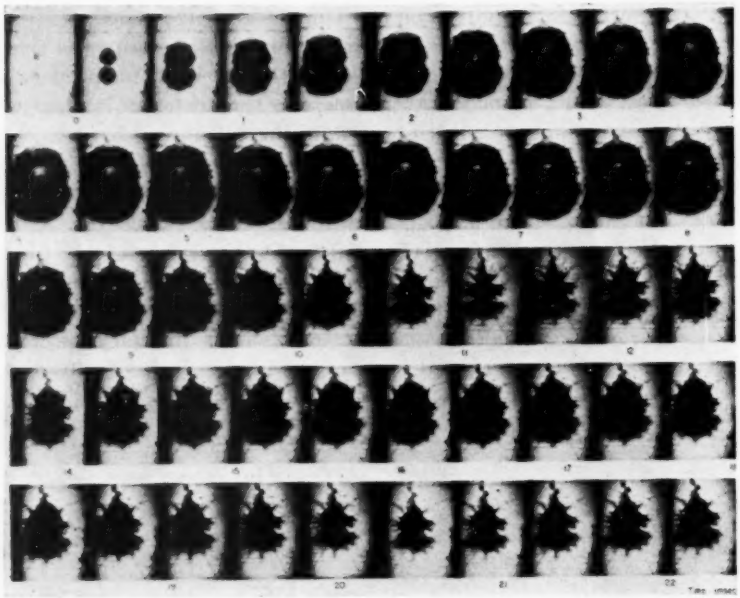

Fig. 4. Explosion of 25 grams tetryl at 350 ft.

successive expansions and contractions are clearly shown. The unsymmetrical shape of the bubble at its minimum is typical of such explosions in shallow water and is the result of carbon particles left behind in the water by the collapse of the gas globe. Front-lighting was provided by four No. 31 GE photoflash bulbs placed midway between the camera and the charge. A white background was used to silhouette the object. The exposure was made at $f/2.7$ and the camera speed was 2200 fps. The film used was Super-XX Panchromatic Negative. Twice the normal development time in D–76 produced reasonable contrast. The camera was focused by means of a ground glass in air, taking a distance in air three-fourths of the object distance under water.

An oscillating bubble such as is produced by an underwater explosion has interesting characteristics when it is near a surface. Such a bubble is repulsed by a free surface and is attracted by a rigid surface. For example, the bubble from a 1-oz charge when fired just beneath the water surface will go down instead of up. An example of a shallow water explosion is shown in Fig. 5. This photo-

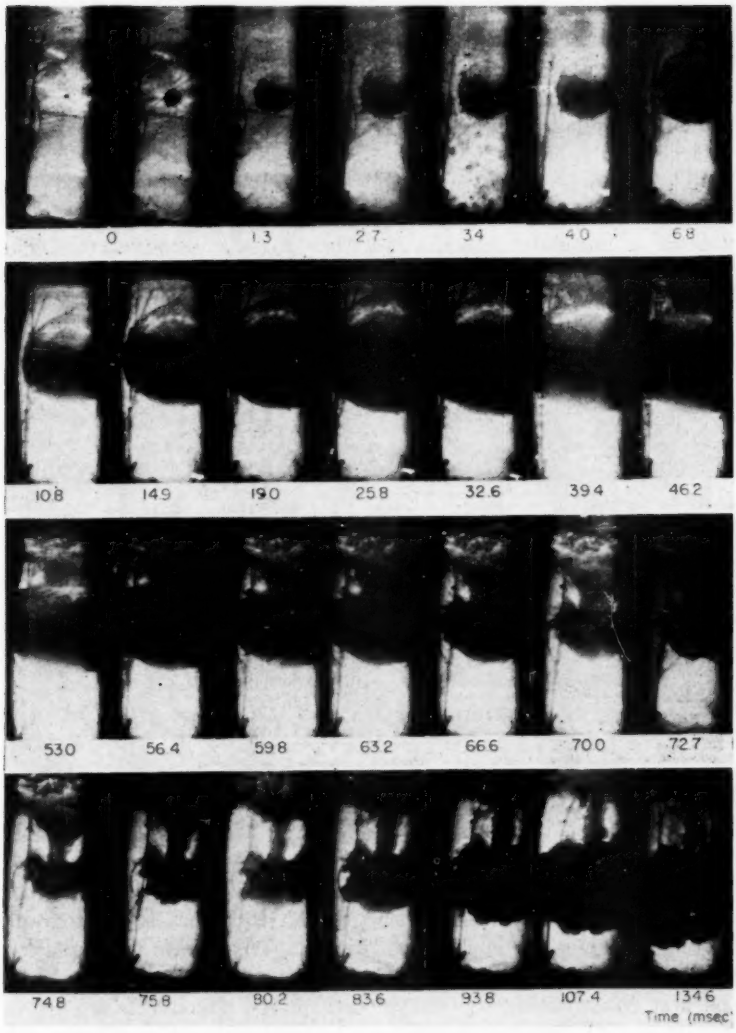

Fig. 5. Explosion of 25 grams tetryl charge 1 ft 9 in. beneath surface.

graph was obtained by using the 35-Mm Fastax camera. Here backlighting was used and two sets of No. 31 photoflash bulbs were set off in sequence in back of a translucent screen behind the charge. The circuit used to fire the flashbulbs in sequence, 50 to 90 msec apart,

is shown in Fig. 6. The 25-gram tetryl charge was 1.75 ft beneath the surface. Small cavitation bubbles resulting from the passage of the shock wave partially obscure the early frames. At its maximum size the bubble is approximately tangent to the water surfaces. As the bubble collapses there is pronounced interaction with the surface. A large tubular connection to the atmosphere permits air to enter the bubble in which the pressure is less than atmospheric when it is close to its maximum. Enough air thus enters the bubble so that its volume at minimum size is larger than for the deeper shots. The tubular space between the bubble and the surface is apparently not a continuous open tube after the minimum, since the bubble once more expands and does not vent.

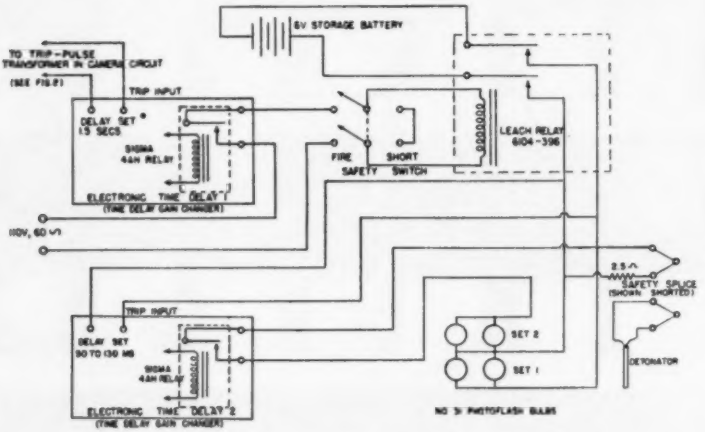

Fig. 6. Sequence firing circuit for two sets of flashbulbs; Underwater Explosives Research Laboratory, Woods Hole, Mass.

An example of the results using the NOL camera to photograph very deep explosions is shown in Fig. 7. This shows the explosion of a 1-lb spherical charge at a depth greater than two miles. Again the first frame shows the unexploded charge which was 3¼ in. in diameter. The detonation light can be seen in the second frame. A linear scale is provided by the black squares in the lower part of each frame. The distance between the inside edges of the squares is 12 in. and between the outside edges it is 18 in. The maximum and minimum bubble diameters are 12½ in. and 5½ in. respectively. The most notable difference in such deep explosions, as contrasted with shallower ones, is that the bubble more nearly retains spherical

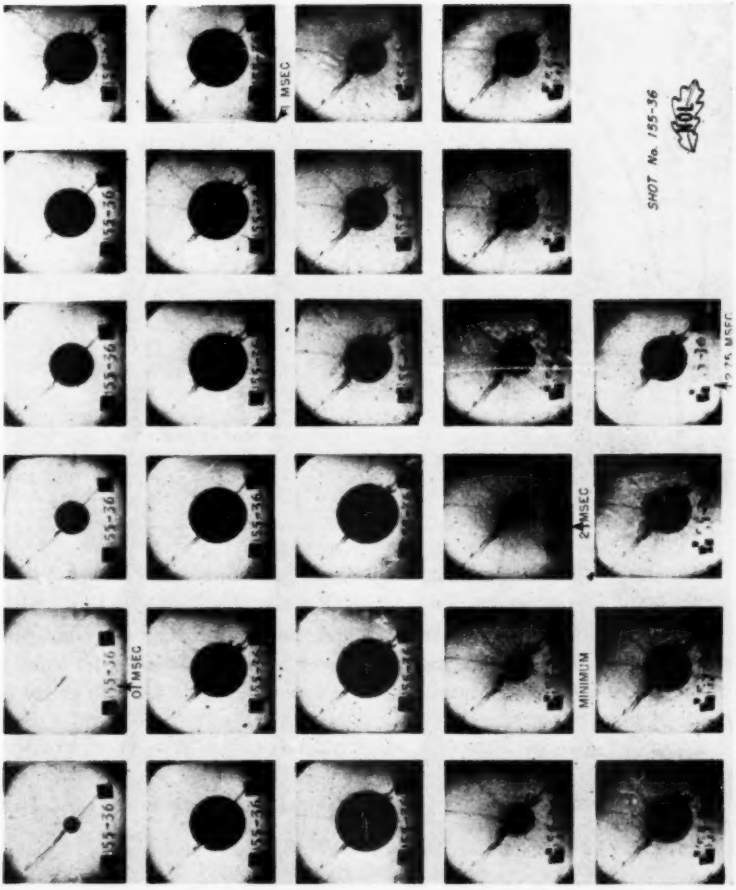

Fig. 7. Explosion of one-pound charge at 12,000 ft.

symmetry throughout its cycle. The carbon particles from the explosion have apparently not progressed outside the gas globe. This has permitted the accurate measurement of the variation of bubble volume with time which is of considerable theoretical importance in the study of explosion phenomena. The reproducibility obtainable from such photographs is illustrated in Fig. 8 in which is plotted the variation of bubble diameter with time for a 1-lb charge at a depth of 6,000 ft.

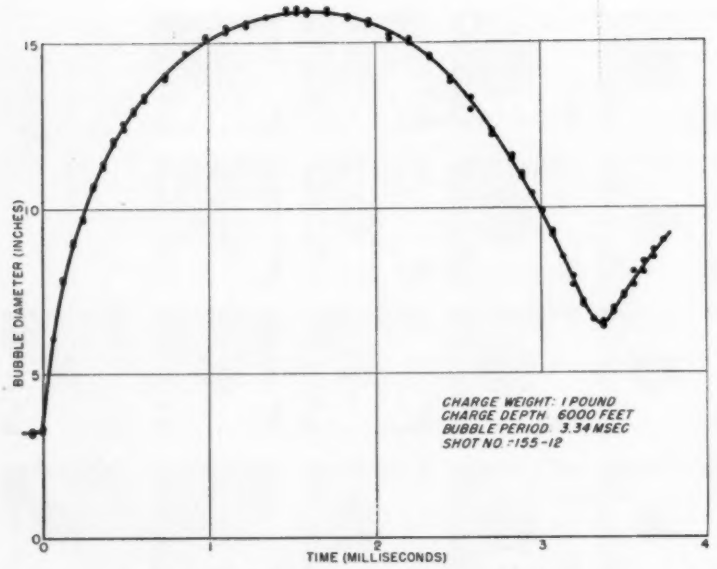

Fig. 8. Variation of bubble diameter with time.

In conclusion it may be pointed out that high-speed photography of explosion phenomena has advanced in the last decade from a curiosity to one of the most valuable tools available for the study of explosions.

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A Heavy-Duty 16-Mm Sound Projector

By EDWIN C. FRITTS

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SUMMARY: An intermittent sprocket pulldown with accelerated geneva drive has its own directly connected synchronous motor. The remaining sprockets and shutter are driven by a second synchronous motor. The two systems, engaged temporarily for starting, run mechanically independent to eliminate shock forces and obtain an inherently flutter-free sound drive. New optics throughout give high picture and sound resolution. Tungsten and arc light sources are provided. Other features include a high-quality amplifier, independently driven accessories, turret accommodation for instantaneous lamp replacement, improved base-up mounting of lamp and improved floor mounting.

Sixteen-millimeter cinematography is a quarter of a century old. From the start, it has found increasing application in organizational functions such as teaching and training, although it was inaugurated to provide personal motion pictures. During the last war, it was used extensively in training and recreational programs, especially by the armed forces. Under hard military usage, projectors wore out rapidly and were generally unsatisfactory for that type of service. This led to the development of Joint Army and Navy specifications, JAN–P–49, for a projector that would be adequate for the services. A great deal of effort was put into these specifications, which were scaled to the ideal objective rather than to one that could easily be attained. A postwar review of the potentialities of 16-mm equipment soon disclosed that amateur projectors were not adequate for testing purposes and that little could be done in evaluating other 16-mm equipment and processes until a new projector was available.

The projector described in this paper was developed to meet the essential features of the JAN specifications. We believe that the intent of all the items is met and that in some respects the requirements of the specifications are exceeded. This projector, named the Eastman 16-Mm Projector, Model 25, was designed to meet the demands of the growing civilian market as well as the needs of the military forces. Also, it was designed in anticipation of marked improvements in the whole 16-mm process.

Presented: April 24, 1950, at the SMPTE Convention in Chicago.

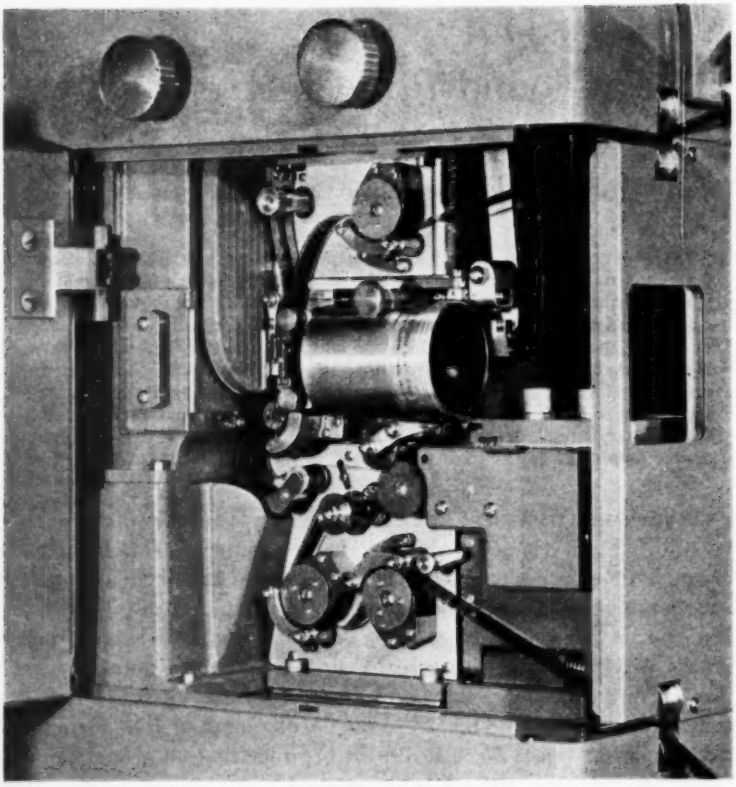


Fig. 1. Film threading path.

Electrical Linkage. A study of the problems of wear, noise, and flutter suggested that much might be gained in designing the mechanical system primarily to control the occurrence and magnitude of extraneous forces that give rise to these three troubles. Movement of the film intermittently in the gate requires a mechanism that has inherently high accelerations. The forces generated are proportional to the masses that are accelerated, and their effect is felt in all the mechanism connected to the intermittent. The intermittent disturbances can be kept out of the other sections of the mechanism by filtering, just as flutter is reduced in conventional projectors.

While the projector is running, there is no other acceleration. If, then, the intermittent is isolated and driven separately, the remainder of the mechanism is protected from these disturbances.

Also, the system, including the shutter and the sprockets, can be designed for a minimum of flutter, flicker, noise and wear. The Model 25 is so divided, each unit having its own motor. The sprocket-shutter mechanism, contained by the main casting, is driven by a four-pole 1800-rpm synchronous motor, which has its rotor mounted on the top end of a vertical shaft. For the intermittent mechanism, a special synchronous motor having a speed of 1440-rpm is provided.

Since the intermittent is separated from the shutter, some means of exact phasing is necessary. To provide this phasing, two special synchro-gears mesh in the usual way during starting, but as the motors pull into synchronism, their teeth float clear of each other. This clearance is provided by removal of alternate teeth from conventional gears. To assure proper contact of the teeth, each of these gears is made of two such cutaway gears assembled side by side with the teeth of one opposite the spaces of the other.

This principle of isolation of mechanical systems by electrical linkage is carried further by the use of three additional motors to drive the take-up spindle, the rewind spindle, and the blower. Each motor is chosen specifically for the particular job it has to do.

Figure 1 shows the positions of the sprockets, gate and shutter housing. Figure 2 reveals the intermittent system complete with its motor and synchro-gear. In Fig. 3 we see this system assembled to the sprocket-shutter mechanism. This rear view shows the motor for the intermittent and its synchro-gear in mesh with an identical gear on the sprocket-shutter mechanism. In order to show these parts, the flywheel for the sound system was removed.

Pulldown System. The pulldown mechanism comprises an intermittent sprocket assembly housed in a separate casting and driven directly by the specially designed 1440-rpm synchronous motor.

Various means of driving the intermittent sprocket, including a "drunken" screw, were considered. However, the geneva star was found to be the most desirable. Here the star does not conform strictly with conventional motion picture practice, because it has eight positions instead of the usual four. A four-frame sprocket would be far too small for 16-mm work, and an eight-frame size seemed the best compromise with respect to the mass of the sprocket and the acceleration in the drive. Basically the driving angle of an eight-position geneva movement is 135 deg, but in this projector, it is accelerated to 57 deg by an off-center driving system. In order to keep bearing loads within reason, we divided this acceleration between two off center driving elements arranged in series, as shown in the skele-

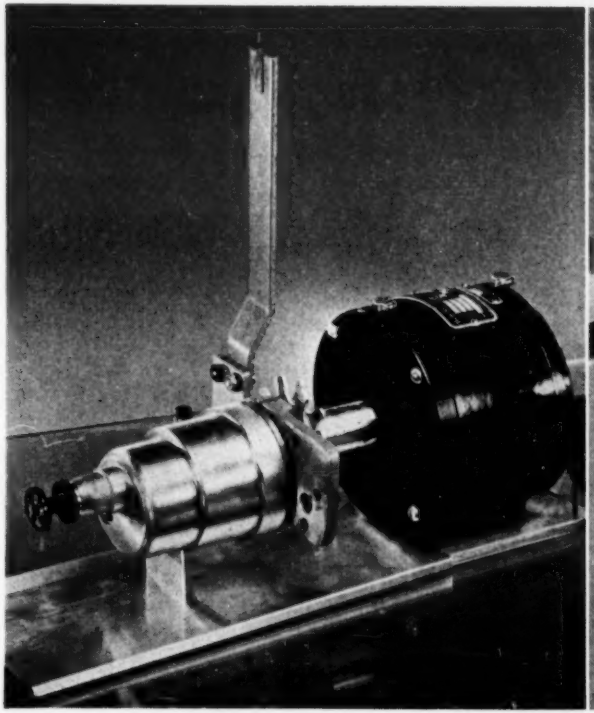


Fig. 2. Intermittent system.

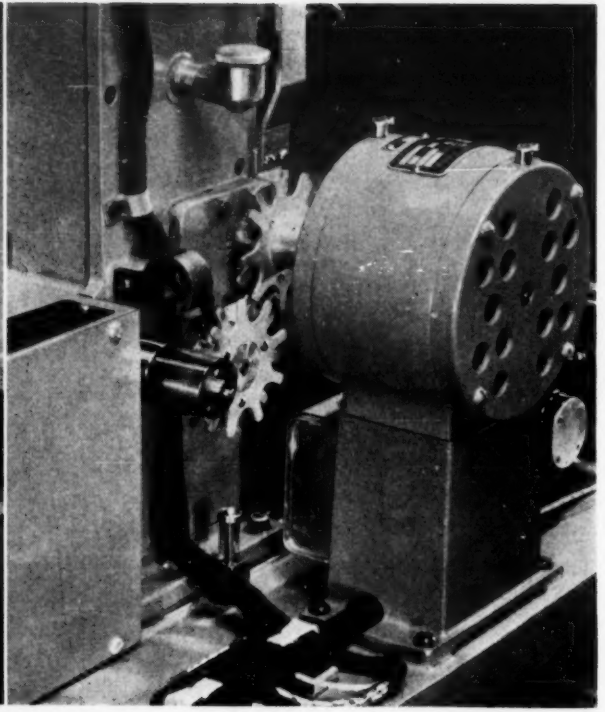


Fig. 3. Assembly of intermittent motor to main mechanism

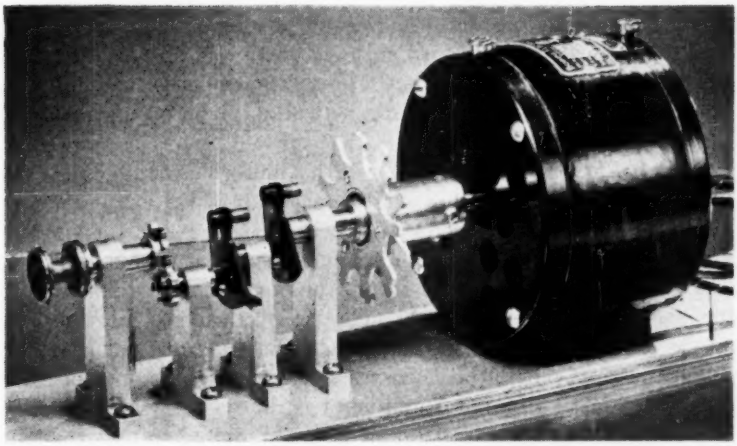


Fig. 4. Skeleton of intermittent system.

ton system (Fig. 4). Viewing from left to right, we see the sprocket, the geneva and its driver, the two balanced accelerators, the synchro-gear and the motor. Inside the hub of the synchro-gear, there is a coiled-spring flexible coupling that has an important function. With this system substituted for a more rigid coupling, there is a material improvement in the quietness of the action. It would be expected that such a flexing element would increase the time required for the pulldown action. However, the oscillating system formed by the spring coupling and the moment of inertia of its load may be tuned to produce the normal 57-deg pulldown. In a model of the projector adapted to television, this tuning is adjusted to produce an action somewhat less than 50 deg.

The intermittent assembly is fitted with two mounting trunnions that are concentric with the sprocket. Thus the unit can be rotated for framing by means of the lever shown in Fig. 2. This lever engages an eccentric on a shaft that extends to an external knob.

Because of the precipitous change from positive to negative acceleration, which is characteristic of the geneva movement, any gears with their necessary backlash in the drive train would be subjected to shock forces. Furthermore, the oscillatory nature of the drive through the flexible coupling would aggravate this trouble, but the use of the 1440-rpm motor eliminates the gearing that would otherwise be needed, thus precluding its troublesome backlash. Two of the three remaining elements that could introduce backlash are the slots and splines of the accelerators. Since they have an

appreciable area of contact, which is not possible with gears, the film of oil between them effectively cushions these forces. Thus a quiet, durable mechanism is obtained. The third element is the pin of the geneva movement. This is made with high precision and has also the benefit of the oil bath.

The 1440-Rpm Motor. The rotor of this motor has five poles. The stator has four poles, each wound in one-fifth of the circumference. At a given instant, the motor is polarized as shown on the right of Fig. 5. In a conventional motor, such as the one at the left in Fig. 5, once synchronous speed is achieved, the poles of the rotor maintain the same polarity unless the motor is overloaded. In this new motor, also, each pole of the rotor maintains the same polarity as it passes the four poles of the stator. But as it passes the open position in the stator, it "loses step" and is forced into a reversal of polarity as it faces the next stator pole. The time required to pass the four poles is $\frac{1}{120}$ sec, the same as required for one revolution of a conventional 1800-rpm motor. However, the rotor has turned but $\frac{4}{5}$ of a revolution during this time. Thus its speed is 1440 rpm.

Sprocket-Shutter System. Ordinarily, the hunting characteristics of synchronous motors cause excessively large shock forces in gearing when parts, such as a shutter, having large moments of inertia are included in the mechanism. This condition, much as in the case of the intermittent, would cause noise, rapid wear of the gears, and flutter in the sound system. In this projector, a protection is

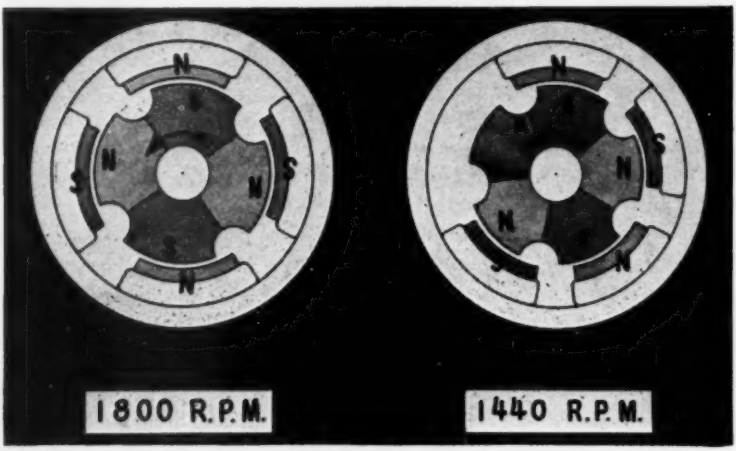


Fig. 5. Diagram to show 1440-rpm motor action.

afforded by a spring coupling between the shutter and its shaft. Thus the reaction torque is reduced, and the hunting of the motor is suppressed. The single-bladed shutter runs at 2880 rpm to give two interruptions of the light per frame of film. It was placed as near the gate as possible in order to provide the minimum angle for covering the light beam.

All three continuous sprockets feed twelve frames of film per revolution. The film is guided with minimum side clearance through these sprockets. They are provided with separate, spring-actuated rear flanges that permit free passage of splices that are not aligned perfectly laterally. All sprockets are of hardened steel.

The problem of meeting all requirements in constructing the gate is perhaps the most difficult in designing any projector. It always seems necessary to make some compromises. We use projection lenses that will resolve at least 90 lines/mm over the whole frame if the film is flat. These lenses were described by W. E. Schade[1] at the Fall 1949 meeting of SMPE. However it is a problem of long standing to hold a film flat against its normal curl and against the thermal distortions caused by the light beam. Here a compromise has been made in curving the gate to a radius of 3 in. When the focus is adjusted to obtain the best average definition for the center and the edges of the screen, a dynamic resolution of 60 lines/mm is obtained. This curved construction also insures against scratching of the film, caused by contact between the gate and the picture and sound areas of the film. For threading, the gate is moved forward with the lens, and it returns to position with the focus of the lens undisturbed. As in framing, focusing is controlled by a knob on the outside of the case. The pivots of this linkage are spring-loaded to take out backlash, and the knob is provided with a lock. Four sapphire pads are used for side-guiding the film.

General Structure. The lamphouse is mounted on a casting that encloses the blower, which is mounted directly on the shaft of a 1725-rpm induction motor. This assembly is mounted on a base casting, as are the assemblies containing the intermittent motor, the main mechanism, and the pre-amplifier. An enclosing case is carried by the same casting. The supply arm mounted on the case completes the projection-head assembly. This whole combination is supported on a pedestal-cabinet that places the projector the correct distance from the floor. This is shown in Fig. 6, which shows the projector adapted for arc illumination. If the arc lamphouse and the rectifier are covered, the appearance is that of the tungsten model.

A platform pivoted about a hinge pin at the top rear edge of the

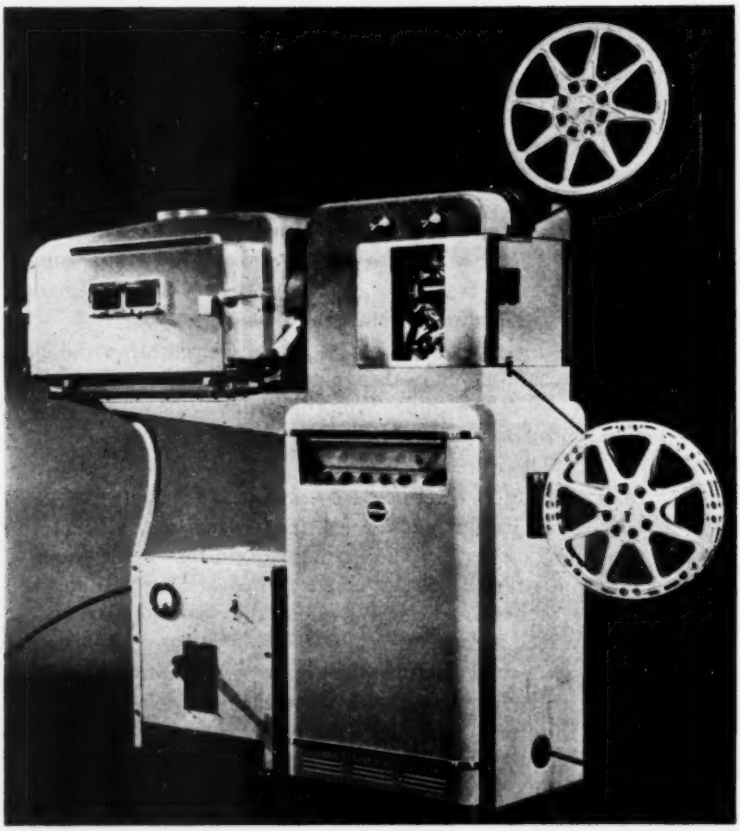


Fig. 6. Complete arc model of projector.

pedestal holds the projection head. It can be tilted, by means of a jackscrew inside the front of the pedestal, for projection to a screen located above or below a horizontal plane through the lens. Two positions for the hinge pin provide two ranges of tilt. The pedestal also supports the take-up arm.

Tungsten Illuminating System. A base-up, 1000-w, 10-hr lamp with an improved basing ring is used. This new method provides more accurate alignment of the filaments, better candle-power maintenance, and improved ventilation. A dual lamp support, Fig. 7, permits rapid replacement of a burned-out lamp. Without stopping the projector, the operator can quickly swing out the old lamp and move a new one into place by means of the lever shown. Then the

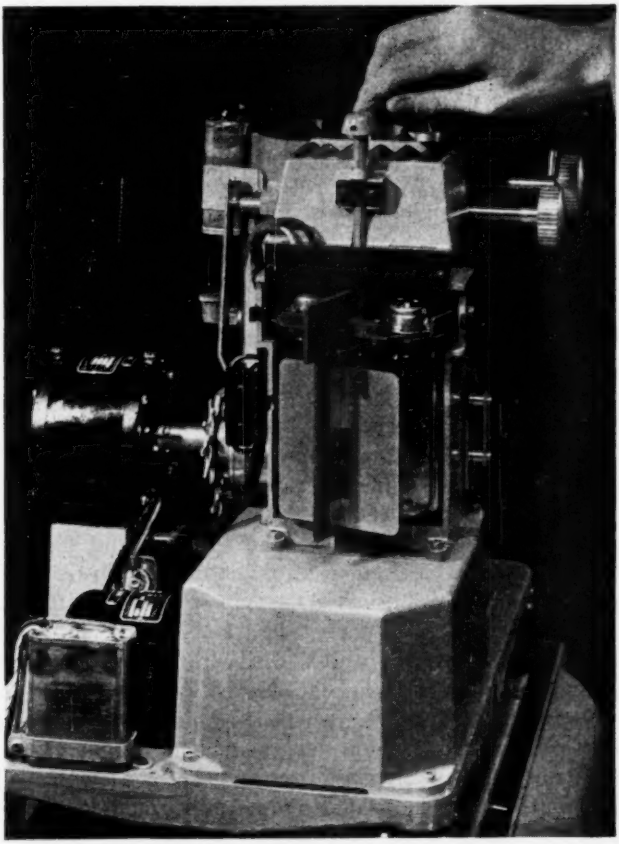


Fig. 7. Turret holder for tungsten lamps.

defective lamp can easily be removed from the top for replacement. A specially designed condenser provides the $f/1.5$ cone of light needed for the objective lenses.

Arc Illuminating System. For arc illumination, the tilting platform is replaced by one that is extended to carry the lamphouse for the arc. Of special design and styling, this arc lamp is made by the Strong Electric Co. A condenser that supplements the mirror is placed in the same position as the condenser for the tungsten lamp. A heat filter located immediately in front of the lamphouse is essential for black-and-white film, but it can be swung out of position for color film.

The Sound System. Three rather distinct functions characterize a sound system. First, the film must be moved with a high degree of uniformity of motion and in a precise location past a scanning position. Second, the film must be scanned with a light beam of proper dimensions. Third, the modulated light from the film must be converted into a modulated electrical signal, and this signal must be amplified for reproduction.

From the foregoing discussion, it will be seen that particular pains have been taken to meet the first requirement, in that the film-driving mechanism was designed as an inherently flutter-free system. It is isolated completely from disturbances originating in the intermittent movement, and the spring coupling for the shutter minimizes the effect of hunting in the motor. Other features provided to meet the requirement include the following: the linkage between the motor and the sound sprocket is through a single-stage worm and worm wheel; the ball bearings carrying the sound drum shaft are mounted in a quill to assure optimum alignment; and the sound sprocket is designed after Chandler[2] to minimize flutter arising from a lack of match in pitch between the sprocket and film. Thus the system is designed throughout for a minimum of flutter.

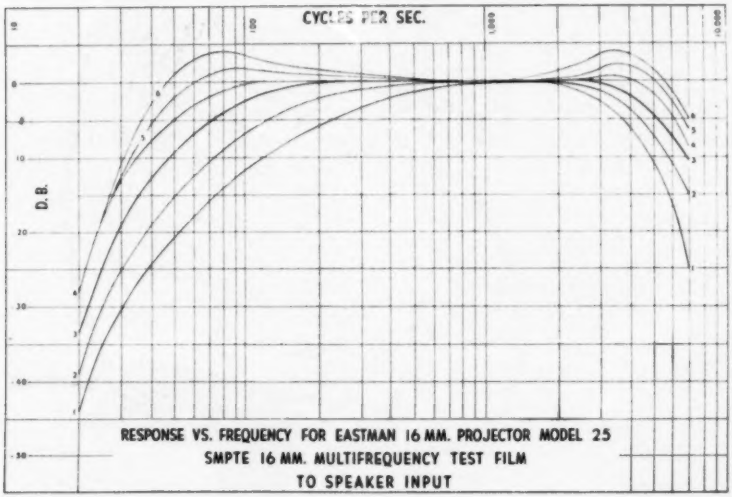
Between the sound drum and the sound sprocket the film passes over an idler mounted on a spring-held arm. The oscillation of this arm is viscously damped by a film of silicon fluid. Tension in the loop is provided by an eddy-current drag between an aluminum disc on the flywheel and a fixed permanent magnet. A separate take-up sprocket provides a free loop on the other side of the sound sprocket in order to keep the functioning of the sprocket constant as it feeds the film from the sound loop, and to protect the sound loop from disturbances originating in the take-up.

The "slitless"-type sound reproducer is essentially as described by McLeod and Altman.[3] An image of the filament of the exciter lamp is formed on the film. An intermediate image formed by a special curved cylindrical element is free of filament character. It is 0.05 of the width of the source, is curved toward the objective, and is limited in length by a suitable field stop. This intermediate image, in turn, is focused on the film, at a further reduction of 3 to 1 by a highly corrected microscope objective, as a flat image that is uniform in width and in light intensity throughout its length.

The last point is necessary in order to reproduce variable-area tracks at reasonably low distortion values. Also, the level of illumination must be sufficient to give a high signal-to-noise ratio. Our measurements of distortion are in terms of intermodulation obtained

with especially prepared, variable-area test films. Since it is difficult to evaluate the width of the slit by straight optical methods, the equivalent value is derived from the amount of attenuation of the high frequencies on SMPTE 16-Mm Multifrequency Test Film. The reference level for noise measurements is obtained from the SMPTE 400-Cycle Signal-Level Test Film.

It is well known that the reproduction characteristics of commercially produced 16-mm films vary over a wide range. In the absence of precision projection equipment, it has been difficult to demonstrate the ultimate quality of either picture or sound. This projector is designed for best reproduction of films made according to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RESPONSE VS. FREQUENCY FOR EASTMAN 16 MM. PROJECTOR MODEL 25
SMPTE 16 MM. MULTIFREQUENCY TEST FILM
TO SPEAKER INPUT

Fig. 8. Response versus frequency curves.

the most advanced production practice. At the same time, it is necessary to handle the full range of quality encountered in films coming from current production. Added to this is the problem of the great variations in listening conditions encountered in 16-mm operation. A wide range of equalization to meet these conditions is provided by step-switch controls on both the low and high frequencies. The curves for these steps shown in Fig. 8 represent the response from SMPTE 16-Mm Multifrequency Test Film.

Electronic System. The electronic system is divided between a preamplifier on the projector head and an assembly mounted in the pedestal, with controls as shown in Fig. 6. In the latter assembly,

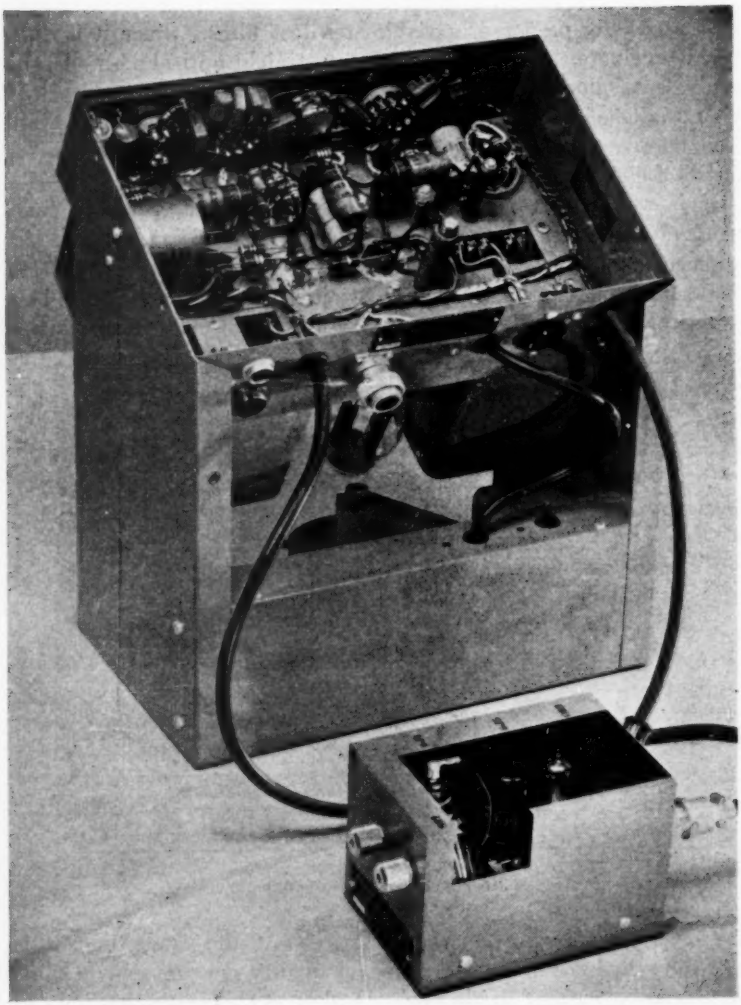

Fig. 9. Amplifier and power supply system.

there is the main amplifier and a d-c power supply for the exciter lamp and the heaters in the pre-amplifier. Figure 9 shows the complete electronic system dismounted and open for servicing. This equipment was engineered in cooperation with the Altec Lansing Corp. and is manufactured by them. It is designed primarily to drive their 604B or 800 loudspeaker. The 604B is supplied in a special

cabinet styled to match the projector, but the 800 is their standard, unmodified speaker. Altec Service Corp. will supervise the installation of the equipment and offer their facilities for servicing it.

Controls. The main power switch connects the system in the following sequence:

1. All circuits are off, but it is possible to energize the rewind circuit by means of the lever on the take-up arm.
2. Blower, rewind, and take-up are on, the last two at reduced voltage, as described below.
3. Blower, take-up at full voltage, and the two motors for the mechanism are on.
4. To point 3 is added the projection lamp for full operation.

After the projector is threaded and the switch is set on position 2, the torque motors located in the two arms are operated at reduced voltage to take up all slack film and pull it gently against the sprockets. This part of the threading, therefore, is assured before projection is started. At the take-up, this elimination of the slack minimizes the possibility of damaging the film as it tightens. At the supply spindle it serves the same purpose, and it also prevents overrunning of the supply reel. Both the torque and the speed of the take-up are adjusted to accommodate a minimum reel-hub diameter of 4⅝ in. Operation of the lever on the take-up arm disengages the take-up motor and puts full voltage on the rewind motor in the upper arm.

Lubrication. Lubrication of the intermittent is by an enclosed splash bath, while the shutter-sprocket mechanism is flooded with oil from an impeller pump on the bottom of the vertical shaft. Ball bearings are used whenever feasible, and all other bearings are designed for infrequent attention.

SPECIFICATIONS

PICTURE

Lenses: Focal lengths of 2, 2¼, 2⅝, and 3 in. All luminized and all $f/1.5$.
Resolution of lens: At least 90 lines/mm over a flat field.
Dynamic Resolution: 60 lines/mm.
Light Source: Tungsten 1000-w, 10-hr lamp,
Improved base-up mounting,
Arc, 46-amp, nonrotating, positive, high-intensity, with 7-mm positive, and 6-mm negative copper-coated carbons,
11-in. mirror with supplementary condenser lens. Carbon trim for 80 min.
Shutter transmission: 60% with two interruptions per frame.
Illumination: Shutter running, no film;
Tungsten: 450 lm;
Arc: With heat glass for black-and-white film, 2000 lm;
Without heat glass for color film, 2500 lm;
Steadiness: Horizontal unsteadiness less than 0.00025 in.,
Vertical unsteadiness less than 0.0005 in.

SOUND

Flutter: Less than 0.2% rms.
Equivalent Slit Width: 0.0003 in.
Intermodulation Distortion: 5% including scanning beam and amplifiers.
Signal-to-Noise Ratio: 55 db, using SMPTE 400-Cycle Signal-Level Test Film.

GENERAL

Elevation: 10 deg above horizontal, 17 deg below horizontal.
Weights:

Projection head	90 lb,
Pedestal with amplifier	165 lb,
Complete tungsten model	255 lb,
Complete arc model with rectifier	640 lb.

Dual Projection: Common amplifier and instantaneous change-over device.

CONCLUSION

The ultimate technical possibilities of 16-mm cinematography are far from being realized. But as each step of forward progress is made, we can see that the potential uses of more highly developed equipment and processes are great indeed. By careful selection of films this projector will demonstrate the quality attainable in individual items such as picture definition, steadiness and sound resolution. At present it is seldom that one film has high quality in all these respects, largely because of the lack of adequate equipment at some point in the production of the film. However, much work is now being done, and the day may not be far off when 16-mm motion pictures come into their own for more serious semiprofessional and professional uses. We believe that this projector, in all functional respects, now raises the limits imposed by projection apparatus above those set by other equipment and processes. We offer it as a precise tool to be used in bringing to pass this day of realization for 16-mm motion pictures.

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Interference Mirrors For Arc Projectors

By G. J. KOCH

Development Dept., Camera Works, Eastman Kodak Co., Rochester, N.Y.

SUMMARY: A large fraction of the radiation from an arc lamp consists of infrared and ultraviolet energy. By coating the arc mirror blank with multilayer interference films instead of with silver, the major portion of the visible light can be reflected while most of the infrared and near ultraviolet radiation is transmitted. Hence, this type of mirror reduces film distortion caused by overheating, and because of the selective nature of the reflection, it affords a means of controlling the color quality of the illumination.

One of the basic problems that must always be faced in the design of high-intensity projectors is the possibility of overheating and buckling the film. This difficulty is particularly acute in the case of motion picture film projected by arc lamp illumination, where a great deal of energy is concentrated on a small area of film. The customary approach to this problem is to absorb the troublesome infrared radiation with a heat-absorbing glass placed between the light source and the film.

Another approach to this problem is the use of multilayer interference filters to separate the visible light from the infrared and ultraviolet radiation. Interference filters designed to transmit visible light and reflect infrared and ultraviolet have proved useful, but their effectiveness is restricted by the limited band of infrared energy which they reflect. Hence, such filters are usually less efficient than heat-absorbing glasses. They are useful, however, as supplementary filters or in applications where high efficiency is not necessary and where breakage of heat-glass is a major problem.

Much more nearly complete separation of light and heat can be obtained if a multilayer filter is used in the inverse manner, that is, to reflect the light and transmit the infrared and ultraviolet radiation. The mirror in an arc lamphouse is particularly well suited for this purpose. If the mirror blank is coated with interference films instead of with silver, most of the visible light can be reflected, and most of the infrared and near ultraviolet radiation transmitted as illustrated in Fig. 1.

Presented: April 24, 1950, at the SMPTE Convention in Chicago.

The interference films shown in the diagram consist of four to eleven layers of transparent or semitransparent materials of alternately high and low refractive index. There is a wide variety of materials, including dielectrics and semimetals, that have optical properties suitable for this purpose. Magnesium fluoride or sodium aluminum fluoride are the customary low-index materials, and zinc sulfide or titanium dioxide, the usual high-index materials. The thickness of the films is controlled so that visible light is reflected from each film in phase with the light reflected from the other films; hence, the combination produces high reflection. In general, however, for wavelengths outside the visible region, the component reflections are out of

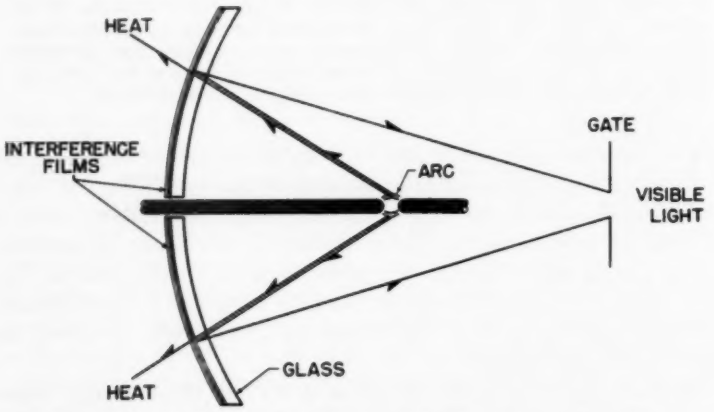

Fig. 1. Simplified diagram showing position of arc, mirror and gate.

phase, which results in low reflection and high transmission. Thus, the multilayer coating is a selective mirror that reflects visible light and transmits infrared and near ultraviolet radiation.

Figure 2 includes a curve showing the approximate reflectivity versus wavelength for an interference mirror of this type. A second curve showing approximately the spectral reflection of a silvered mirror is shown for comparison. It reveals the large reduction in reflection in the infrared and near ultraviolet parts of the spectrum secured with the interference mirror. In fact, for infrared and near ultraviolet radiation, the thin films act as low-reflection coatings, allowing those regions of the spectrum to pass through the mirror with little attenuation. But for visible light the films act as high-reflection coatings with a reflectivity equal to or greater than that of a silvered mirror.

The exact shape of the reflection-wavelength curve depends primarily on the following factors: the reflectivity at each film interface, the number of layers, the optical thickness of each layer relative to that of the other layers, the dispersion and absorption characteristics of the materials, and the angle of incidence of the light. The calculations involved in the design of efficient combinations are so formidable that graphical and analogue computing devices have proved most helpful.

The films are deposited on the glass mirror blank in a high-vacuum coating system. The procedure consists in successively evaporating

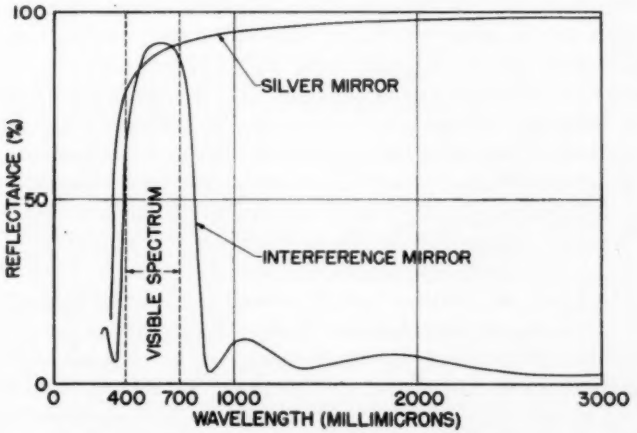

Fig. 2. The spectral reflectance of a multilayer interference film compared with that of a silver film.

the required number of layers on the glass blank, which rotates continuously in the high-vacuum chamber. Critical control of the thickness of each layer is obtained by the use of a photoelectric monitoring system that indicates the thickness of the material as it condenses on the glass. Successful mirrors have been made with the coatings on the front surface instead of the rear, but damaging of the multilayer films by the sputtering of the arc makes such mirrors less practicable. A high-temperature lacquer sprayed and baked on the films protects them from mechanical damage. It has been found that the lacquer actually improves the optical efficiency of the layers by increasing their transmission in the infrared region.

Although mirrors made in this way are still in the development stage the tests made on them have been very encouraging. Measurements

on the first arc lamp samples showed that the illumination at the gate contained more visible light and less total radiation than that obtained from a standard silvered mirror with light shade of Aklo heat-absorbing glass in the beam. Even the most efficient heat-absorbing glasses show a gradual decrease in transmission from wavelengths of 600 to 1000 millimicrons; hence they allow an appreciable amount of near infrared energy to reach the film. But interference mirrors are not limited by this fundamental absorption characteristic. Both calculations and experiments have shown that considerably sharper cuts can be obtained with interference reflectors than with silvered reflectors used with heat-absorbing glasses. In the ultraviolet region also, the decrease in reflection with wavelength is sharp but detailed measurements have not yet been made. Certainly the peak at 390 millimicrons in the arc emission curve is greatly reduced.

A second advantage of such mirrors is that they eliminate the problem of breakage of heat-glass. Since the interference films absorb little radiation, and since they are distributed over the large area of the mirror blank, they do not get nearly so hot as a heat-absorbing glass. Actually, the absorption of infrared by the glass mirror blank itself is largely responsible for the temperature rise observed.

Probably the most important advantage these mirrors have over a silvered mirror used with a heat-absorbing glass is the control that can be attained over the color quality of the light. By proper adjustment of the thickness of the interference layers, the color of the reflected light can be varied over a wide range. This factor is of major importance for the projection of color film. Our experimental arc mirrors for 16-mm projectors are coated so that light from a high-intensity arc is modified to give satisfactory color balance for the projection of Kodachrome film.

The development work on this type of mirror is still in the laboratory stage. Further details, such as life tests and more efficient combinations of layers, are being investigated. When these tests are complete we plan to try the coatings on 14-in. mirrors for tests in 35-mm arc projectors.

Engineering Committees

New Release Print Leader

In July, we prematurely announced the availability of a newly proposed release print leader. Contrary to expectations, the first prints were found unsatisfactory after trial at a few of the New York television stations; consequently, another version was made up and prints were distributed to all of the television networks in New York. On Friday, September 8, Charles Townsend's subcommittee met and approved this version for limited trial distribution. After consultation with Dr. Garman, Chairman of the parent committee, and Fred Bowditch, Engineering Vice-President, it was agreed to make up a fairly substantial quantity of both negatives and prints. All of those requesting samples as a result of the July announcement, as well as others known to have an interest in this project, have now been supplied.

There has been some concern among those responsible for this work that rather general distribution at this time may cause difficulties. It has been the hope from the start that one leader can be developed, which will serve the theater, television and the 16-mm fields equally as well. If the trial leaders now being distributed should get into general use, it would certainly mean the existence of two leaders and the possibility of considerable confusion; therefore, a letter was sent with each sample, requesting the recipients to use the leaders only for experimental purposes and to withhold any wider use until the committee has had an opportunity to review all comments.

Committee Ballots

During the last six months, members of Engineering Committees have been extremely lax about returning their ballots on proposed standards, recommendations or committee reports. Often when members feel that they have no comments or critical interest in a particular subject, they fail to take any action to notify Society headquarters to that effect. Consequently, the balloting is not closed because of the belief that the missing votes represent objections to a proposal. It is realized that in some cases committee members need time to make a thorough investigation before casting a formal ballot. In those cases, however, it would be most helpful if such were reported so as to save the time and money spent sending out repeated follow-ups.

At the present time, six engineering ballots are in process. One, "16-mm Review Room Characteristics," was mailed on May 29, 1950. The ballot was sent to 72 committee members and to date just half have been returned. This is a very poor response for a project that two years ago was considered important enough to warrant considerable activity. Listening tests and meetings were held in Astoria, New York City, Washington and Chicago. Equipment was shipped around and committee members spent time and money traveling to those sessions. After all of that time and effort, it is most unfortunate that the project should be held up merely because members neglect to vote.

Possibly, there is some fault in our method of operation which is causing the delays. If this is true, we would greatly appreciate your suggestions.

Book Reviews

Questions and Answers in Television Engineering, by Carter V. Rabinoff and Magdalena E. Walbrecht

Published (1950) by McGraw-Hill, 330 West 42d St., New York 18. 283 pp. + 2 pp. appendix + 16 pp. index. 175 illus. 6 × 9 in. Price $4.50.

Although book lists today abound with volumes whose titles include "television," by far the majority deal with television receiver servicing or with the theory and design of receivers. Books which treat television as a many-faceted field, no part of which is more important than the other parts, are not common. This volume is such a work.

It is divided into twelve chapters: Antennas, Radiation, and Transmission Lines; R.F. and I.F. Amplifiers, Converters, and Oscillators; The Limiter, Clipper, Detector, and Sync Separator; Video Amplifiers; Deflection Systems; Cathode-Ray Tubes, Camera Tubes, and Photoelectric Cells; Images and Patterns; Optical Systems and Illumination; Transmitters; Standards, Laws, and Regulations; Receiver Principles, Filter Theory, and Power Supplies; and Analysis of Two Typical Receivers.

The book is intended as a reference source for those who are in the television field and as a "semi-textbook" for those who need to clarify and organize their knowledge. It is singularly successful in both roles, primarily because of the adoption and intelligent treatment of the question-and-answer technique. A writer whose object is simply to give an explanation of a certain rather wide subject too often tends to ramble, to lack organization, to use too many words, and to avoid being specific.

The authors here, however, have voluntarily bound themselves to the asking of the logical questions and to answering them specifically, succinctly and precisely. In this way, they have made each piece of information definitely useful in doing a certain job or in the study of a particular phenomenon or piece of equipment. They have paralleled the thoughts of the reader who uses the book for reference, for his reason for referring to the book in the first place is because he has a question in mind.

As a learning aid for readers who need to consolidate their knowledge the book is valuable because the questions have been chosen to carry the subject through in logical order. The reader who starts at the beginning of the book need not be an electronics specialist. He is introduced to the special character of v.h.f. propagation, the reasons for antenna design and the practical calculations, receiver inputs and other receiver circuits. The explanation of scanning methods leads into a discussion of cathode-ray tubes and photocells, which naturally carries forward to images and patterns. These three subjects are all linked with both transmission and reception. The next section, on optical systems and illumination, will be quickly understood by motion picture men and will make the pieces of the previous explanations fall into place neatly.

The section on transmitters is basic enough for instruction, but is also specific enough, with elementary calculations and figures to be of aid to the television specialist. Many of these questions, in fact, parallel those in FCC licence examinations, and may be used as review material for prospective examinees. In this section there is particular reference to the special applications of motion picture techniques to television.

The important definitions, FCC regulations, and standard practices in transmission are given in the standards section. The receiver section is devoted largely

to the points that do not ordinarily get full treatment, such as projection systems, filter configurations, and power supplies. The final chapter is a stage-by-stage breakdown of an RCA and a GE receiver from a design standpoint, with, in many questions, the interesting and instructive approach of asking the "why" of certain design provisions. The appendix contains additional information on proposed u.h.f. channels, metropolitan and community stations, interference ratios, allocations, power radiation regulations, and auxiliary (mobile pickup and relay) stations. The index is unusually complete and helpful.

This volume is not large enough to contain all the information that every reader might need at some time or other; but it is certainly a highly useful one to keep in any technical library, especially in conjunction with some of the more conventional books on receivers and other specialized divisions of the television field.—Richard H. Dorf, Television Consultant, 255 W. 84th St., New York 24.

Réunions D'Opticiens, Tenues a Paris en Octobre 1946, Textes rassemblés par Pierre Fleury, André Maréchal et Mme. Claire Anglade, Institut d'Optique, Paris

Published (1950) by Editions de la Revue d'Optique, 165, Rue de Sèvres; 3 et 5, Boulevard Pasteur, Paris (15e). xv + 673 pp. 6 × 9 in. Price on request.

This is a collection of 131 scientific papers presented by 109 authors at an international convention held in Paris in October, 1946. The volume contains numerous illustrations. It represents a summary of all modern research trends in the field of theoretical and applied optics.

The volume covers the following topics: basic theoretical studies, theory of aberrations, structure and perception of optical images, optical instruments, optical surfaces and materials, optical measurements, sources and receptors physiological optics and color, ophthalmological optics, spectroscopy, molecular optics, polarimetry, astronomical and atmospherical optics, and corpuscular optics.

While being of much interest to anyone interested in fundamental optical investigations, this volume is not intended as a textbook nor can it be used as such; and, of course, it is not an engineering manual. For this reason, a practical motion picture engineer will not find in this volume much that is of direct use to him, unless he wants to make himself acquainted with powerful new ideas and tools which at some future time may considerably influence motion picture art and engineering.—Dr. K. Pestrecov, Bausch & Lomb Optical Co., Rochester 2, N.Y.

Photographie Instantanée et Cinematographie Ultra-Rapide, par P. Fayolle et P. Naslin

Published (1950) by Editions de la Revue d'Optique, 165, Rue de Sèvres; 3 et 5, Boulevard Pasteur, Paris (15e). Price on request.

Messrs. Fayolle and Naslin have undertaken to produce a text on high-speed photography, something that has been needed for a long time. There have been previous publications but they have generally covered only a small portion of the field. Tulpholme in his book, *Photography in Engineering*, discusses high-speed photography in one chapter. Other phases have been covered in *Lehrbuch der Ballistick* and in other numerous papers. Now, Messrs. Fayolle and Naslin have consolidated much of this lore in one text.

The summarization that they have given covering the optical problems of high-

speed photography is well done. The discussions of light sources and the various cameras which are in existence are good; and, for a text, to serve as a background in high-speed photography, it is invaluable today, if for no other reason than that no other such source exists.

There are, however, some exceptions to be taken to the text and your reviewer has written the authors that they have neglected many of the advances that have been made in the United States in the last two or three years, advances which have been described in the symposia on high-speed photography held by the Society of Motion Picture and Television Engineers. Such include the high pulse-rate Edgerton flash unit, the late advances in flashtube design by General Electric, the design of rotating prism cameras, and the development and use of high-speed motion picture cameras in this country. Furthermore, there is no reference to the incandescent lights which have been developed by General Electric for high-speed photography. Your reviewer might be a little biased but he feels that, if rotating prism cameras are discussed, then the two kinds that are manufactured in this country should be discussed rather than confining the description to one. Since the two cameras are about equally popular in this country, an impartial review should include discussions of both.

For those who are seriously interested in high-speed photography, it is felt that this book is a must. Ability to read French is not a requirement for understanding this book quite thoroughly.

It should be noted that the next major project of your Society's High-Speed Photography Committee is to produce an American textbook. Whether that will be chiefly the work of one man or the result of the efforts of the Committee as a whole is not yet established, but there will soon be a text in English in production.—JOHN H. WADDELL, Industrial and Technical Photographic Division Fastax Cameras, Wollensak Optical Co., Rochester 21, N. Y.

Letters to the Editor

Re: Light Measurement for Exposure Control

[The publication of a paper under this title by Don Norwood, May 1950 JOURNAL pp. 585–602, has elicited the following comments.]

I was very interested to read the above noted article, for my development of the Duplex Incident Light Exposure Meter Technique has meant that for the last three years or so I have been working on almost parallel lines.

Before noting some further developments, I hope you will permit me to correct Mr. Norwood's statement on p. 595, in which he claims that his "concept of *Effective Illumination*, which takes into account illumination intensity and relative positions of observer, subject and light source *has not heretofore been crystallized or formulated*" [the latter italics are mine]. In contradiction to this statement, reference may be made to the November 1948 *British Kinematography* containing my article "Exposure Technique for Reversal Materials," from which it may be noted that I described this effect (which I named the "Duplex" technique) over two years ago before a meeting of the British Kinematograph Society in London.

Since reading my paper in 1948, a slight improvement over my originally described "Horizontal Duplex" method has been developed. The new recommended "Direct Duplex" method, which has been worked out by my colleague L. C. Walshe and myself, still consists of taking two readings with an incident light meter (of the flat window type), namely a "camera direction" reading (as

previously recommended) and a "major source direction" reading (as originally recommended for use alone by P. C. Smethurst, who first introduced the incident light meter technique in England in 1936—see his paper in *British Kinematography*, vol. 1, no. 1).

The required exposure for average work is then given by simply taking the geometric mean of the two Duplex readings, i.e., the mid-point on the stop scale between the two readings. For clear-cut conditions this technique will be found to line up almost exactly with the exposure levels recommended by the principal reversal color film manufacturers, and it has proved to be highly successful in practice. It has, incidentally, already been fully described in a book on this subject which is in preparation and will be published in due course . . . .

J. F. DUNN
1 Deneway, Bramhall
Cheshire, England

July 21, 1950

In comparison with Mr. Dunn's statement that he has been working on almost parallel lines for the last three years or so, I should note that my experience with incident light exposure meters date from 1933 when my first incident light exposure meter (of the hemisphere light-collector type) was constructed. That meter was rigorously tested for several years, and patent application was made in 1938 (U.S. Patent 2,214,283).

The principle involved in that meter took into precise account both light intensity and the geometric relationship of keylight, subject and camera, as described in the aforementioned paper.

Work on other types of incident light exposure meters, which are based on the same fundamental principle, has proceeded since that time. See: U.S. Pat. #2,489,664, application filed in 1946; and U.S. Pat. #2,444,464, application filed in 1947. Both applications were filed prior to the time when Mr. Dunn reports the beginning of his endeavors, circa 1947. Explanation was made on p. 585 of May 1950 JOURNAL, that evolving patent protection had made full release of basic data inadvisable until 1948, when the paper was written. The JOURNAL publication showed that the Society received the paper in February 1949.

It has been recognized that some workers in this field have had a more or less hazy realization that more was involved in incident light measurement for exposure control than a simple measurement of light intensity. Various corrective expedients have been proposed by some of these workers, such as pointing a meter with a plane surface light collector toward the camera from subject's position; pointing said meter toward principal light source; aiming said meter toward a point halfway between said light source and said camera; pointing meter at camera and at light source in turn and using a mean reading as suggested by Mr. Dunn. However, none of these makeshift methods appears to indicate a full and clear-cut realization of the basic principles involved in the matter. None of the experimenters have, to my knowledge, brought forth precise and comprehensive formulae such as those shown in (15) and (16) on p. 595 of the May JOURNAL.

I do not agree that Mr. Dunn in describing his Duplex Method in *British Kinematography* has given a clear-cut, well crystallized comprehension of all the factors involved, as well as a formula for accurate solution of the problem. For instance, his formula for calibration of incident light meters was preceded by a quite similar formula on p. 14-6 of the *I.E.S. Lighting Handbook*, published in 1947. Neither formula takes into account the vital factor of geometrical relationship of subject, camera and light source. If this relationship were understood it would seem that it would have been put into Mr. Dunn's formula.

It is of interest to examine under specific conditions Mr. Dunn's recommended method of operation. As an example, we find that Mr. Dunn's Direct Duplex Method would give identical exposure control settings for a *cross-lighted* arrangement (90° keylight angle), and a *back-lighted* arrangement (135° keylight angle), where other factors remain constant. Reference to instructions issued by leading color film manufacturers (see Note 5, my paper) will show that a considerable difference in exposure control setting is recommended for *cross-lighted* and *back-lighted* conditions. The difference is usually about one *f*-stop. It is generally believed that reversal color film will not tolerate an error of one *f*-stop. Therefore Mr. Dunn's "two-readings" method when used with color film under the common conditions described above will give errors which lie outside the acceptance latitude of the film. This also negates Mr. Dunn's statement (next to last paragraph in his letter) that his method lines up with recommendations of film manufacturers....

August 5, 1950

DON NORWOOD
1470 San Pasqual St.
Pasadena 5, Calif.

New Members

The following have been added to the Society's rolls since the list published last month. The designations of grades are the same as those in the 1950 MEMBERSHIP DIRECTORY:

Honorary (**H**) Fellow (**F**) Active (**M**) Associate (**A**) Student (**S**)

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Casterlin, Charles C., Head Paying-Receiving Teller, Hamilton National Bank, Dupont Circle Branch. **Mail:** 3345 Stephenson Pl., N.W., Washington 15, D.C. (**A**)

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Creutz, John, Radio Engineer, Old Dominion Dr., McLean, Va. (**A**)

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Stedman, Dean C., University of Southern California. **Mail:** P.O. Box 766, Cluster, S.D. **(S)**

Swift, William C. G., Sound Engineer, Paramount Pictures Corp. **Mail:** 346 Richbell Rd., Mamaroneck, N.Y. **(A)**

Taraba, Vilem, Technical Manager, State Film Studios, Barrandov, Prague, Czechoslovakia. **(A)**

Young, Charles W., Photographer, Pennsylvania State College Ordnance Research Laboratory. **Mail:** 643 Fairway Rd., State College, Pa. **(A)**

Young, Keith D., University of Southern California. **Mail:** Willard Hall, 942 W. 34 St., Los Angeles 7, Calif. **(S)**

CHANGE OF GRADE

Herold, Ralph E., Audio-Visual Coordinator, Los Angeles Public Library. **Mail:** 5069 Montezuma St., Los Angeles 42, Calif. **(A)** to **(M)**

Morrison, Ernest W., Cameraman, U.S. Air Force, Lookout Maintenance Laboratory. **Mail:** 564 Larchmont Blvd., Los Angeles 4, Calif. **(S)** to **(A)**

Thomas, John W., Radio and Sound Serviceman, 3736 South Michigan Ave., Chicago, Ill. **(S)** to **(A)**

CORRECTION

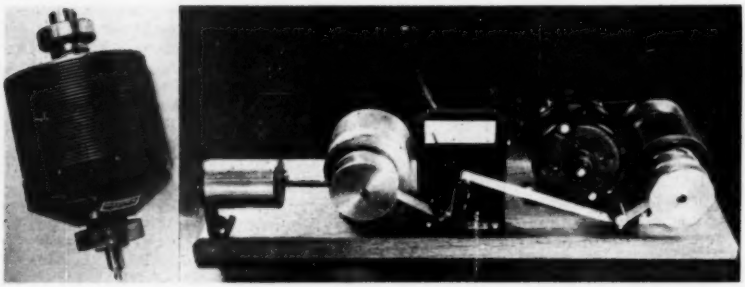
Haines, Robert A., because of a copy-editing error, appears in the 1950 Membership Directory with an address (at St. Louis) which is out of date since 1946. The listing should be:

Haines, Robert A., Senior Engineer, FEC Motion Picture Service, SSS, GHQ, Far East Command, APO 500, c/o Postmaster, San Francisco, Calif. **(A)**

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

All-metal reflectors, made by combining two metals by electroplating, have a front surface protective coating of rhodium which is an element from the platinum family, exceptionally high in reflectivity and reported the only metal available with sufficient reflectance and able to withstand successfully the damaging effects of high-intensity carbon arcs. The manufacturer, Heyer-Shultz, Inc., Cedar Grove, N.J., reports that fabrication to close tolerances permits interchanging similar models made years apart, with a minimum of reflector adjustments by the projectionist.



PM Hysteresis clutches and brakes were recently developed by Duncan & Bailey, Inc., 785 Hertel Ave., Buffalo, N.Y. They provide for smooth application of torque from conditions of 100% slip to zero slip or operate continuously at any slip or torque condition through a wide range of rotational speeds and power capacities. Bearing drag is the only load present when these devices operate in the unenergized conditions and the characteristics of power application depend upon the performance of the control mechanisms employed.

Torque bears a linear relation to control current and for instantaneous application of control power engagement is rapid but shock loads are absent and response time is generally proportional to control power impressed. A typical value for 30 w of applied control power and 100 oz-in. of torque is 100 milliseconds. A one-quarter horsepower unit operating at 1750 rpm has frequency response of 2 cycles per second.

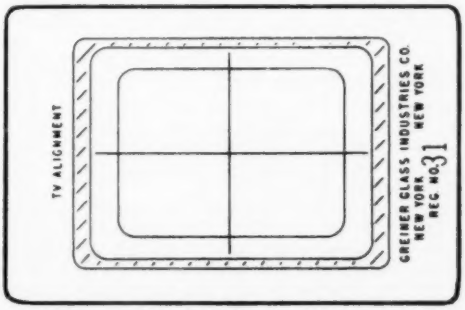
Control current required is roughly one-tenth of the power output of the device when operated as a coupling. Type PM-3 using 25 w of control power will transmit 375 w at 3400 rpm.

With any of a wide variety of servo or external control systems, these units working as either transmitters or drag elements can be used to provide constant speed, torque, tension or repetitive cycling within performance limits of about

1%. Input rotational speeds up to 10,000 cycles are permissible as are rapid cycling operations, limited only by resulting rise in temperature. Design of the housing provides for sufficient heat dissipation and performance is within rated capacities as long as temperature rise does not exceed 300 F for continuous operation.

Illustrations show the external clutch housing and one constant tension application employing two units—one as a transmitter and one as a brake, actuated by a sensing device which responds to changes in diameter of the loaded feed spool. Detailed performance data and dimensions are available from the manufacturer who also designed the FM (fluid magnetic) clutch for specialized and somewhat less severe applications. Magnetic friction grab couplings for industrial applications with torque ratings of 80 in.-oz or 40 ft-lb are also available.

A special viewfinder ground glass for 35-mm motion picture cameras shows the portion of the scene most likely to be reproduced on a home television receiver. This pattern gives the cinematographer an accurate check of the average cut-off losses which must be allowed for in order to have a good visual presentation on television. The etched pattern is based on the first section of the Society of Motion Picture and Television Engineers test film as described and illustrated in the February 1950, JOURNAL, p. 211. The striped area represents the section lost at the time of scanning in the television station. The inside rectangle is approximately 80% of the picture area. Tests indicate that this area is reasonably well reproduced on most home receivers. Television Ground Glass for the Mitchell camera etched with the television aperture is available directly from Greiner Glass Industries Co., 781 E. 142 St., New York 54. Television Ground Glass for other cameras is also available. Prices on request.



Ground Glass × 3

SMPTE Officers and Committees: The Roster of Society Officers was published in the May JOURNAL. For Administrative Committees see pp. 515–518 of the April 1950 JOURNAL. The most recent roster of Engineering Committees is on pp. 337–340 of September 1950 JOURNAL.

Meetings of Other Societies

Audio Engineering Society, National Convention, Oct. 26–28, Hotel New Yorker, New York

Optical Society of America, Oct. 26–28, New York

Theatre Owners of America, Annual Convention, Oct. 30–Nov. 2, Shamrock Hotel, Houston, Texas

Acoustical Society of America, Fall Meeting, Nov. 9–11, Boston

Statement of the Ownership, Management, Circulation, *Etc.*, Required by the Act of Congress of August 24, 1912, as Amended by the Acts of March 3, 1933, and July 2, 1946, of *Journal of the Society of Motion Picture and Television Engineers*, published monthly at Easton, Pa., for October 1, 1950.

State of New York } ss.
County of New York }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Boyce Nemec, who, having been duly sworn according to law, deposes and says that he is the Executive Secretary of the *Journal of the Society of Motion Picture and Television Engineers* and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily, weekly, semiweekly, or triweekly newspaper, the circulation), *etc.*, of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Acts of March 3, 1933, and July 2, 1946, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Name of— *Post Office Address*—

Publisher, Society of Motion Picture and Television Engineers, Inc., 342 Madison Ave., New York 17, N. Y.
Editor, Victor H. Allen, 342 Madison Ave., New York 17, N. Y.
Managing Editor, None.
Business Manager, Boyce Nemec, 342 Madison Ave., New York 17, N. Y.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)
Society of Motion Picture and Television Engineers, Inc., 342 Madison Ave., New York 17, N. Y.
Earl I. Sponable, President, 460 W. 54 St., New York 19, N. Y.
Robert M. Corbin, Secretary, 343 State St., Rochester 4, N. Y.
Frank E. Cahill, Jr., Treasurer, 321 W. 44 St., New York 18, N. Y.
No stockholders.

3. That the known bondholders, mortgagees, and other security holders owning or holding one per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state.)
None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is: (This information is required from daily, weekly, semiweekly, and triweekly newspapers only.)

BOYCE NEMEC, Exec. Secy., Business Manager.

Sworn to and subscribed before me this 21st day of September, 1950.

(Seal) Elisabeth J. Rubino
Notary Public, No. 41-3390800, Queens County.

(My commission expires March 30, 1951)

Sustaining Members

Our Sustaining Members hold several keys to our past and future success.

On the one hand where the Society functions as the official clearinghouse for technical standards on motion pictures and as one part of the standards machinery serving television, our Sustaining Members rely heavily on the collective judgment of 20 engineering committees. They adopt for commercial use many resulting recommendations. On the other hand, they freely support this work through the annual Sustaining fees and their engineers contribute generously to such joint engineering projects by taking active part in committee deliberations. Income from Sustaining Membership fees supports the *Journal* by making possible early publication of important manuscripts.

Future growth in responsibility, membership and prestige calls for enthusiastic support of all Society activities by our current and potential Sustaining Members.

Sustaining Members

OF THE

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

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National Theaters Amusement Co., Inc.
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Neumade Products Corp.
Producers Service Co.
Projection Optics Co., Inc.
Prudential Circuit
Radio Corporation of America, RCA Victor Division
Reeves Sound Studios, Inc.
SRT Television Studios
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Technicolor Motion Picture Corp.
Terrytoons, Inc.
Theatre Holding Corp., Ltd.
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United Amusement Corp., Ltd.
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Westinghouse Electric Corp.
Westrex Corp.
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